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Supporting document for

Towards a smog plan for Ontario

A DISCUSSION PAPER

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D R A F T

SUPPORTING DOCUMENT

FOR

TOWARDS A SMOG PLAN FOR ONTARIO

(A Discussion Paper)

Prepared by

Ontario Ministry of Environment and Energy

JUNE 1996

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SUPPORTING DOCUMENT FOR "TOWARDS A SMOG PLAN FOR ONTARIO"

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INTRODUCTION

This supporting document was prepared by staff of the Ministry of Environment and Energy in support of the discussion paper entitled "Towards a Smog Plan for Ontario". This document is divided into eight sections, each providing further background information on issues cited in the discussion paper.

The discussion paper is a part of a much broader Regional, National and International Plan to deal with the issue of smog. Section A provides details on the developments between federal/provincial and Canada/U.S. governments.

Smog is not an isolated environmental issue. It is closely linked to many other issue such as acid rain, climate change and ozone depletion. Section B describes the linkage of smog with these issues in terms of pollutants and source sectors. This section also identifies the multitude of other environmental benefits that can be gained from a smog reduction program.

Ozone and inhalable particulates and ozone are the two constituents of smog of greatest health concern. There is strong evidence that current levels of these pollutants are affecting our health. Section C provides an up to date review of the available health effects and a brief description of a recently developed approach, which can be used to estimate health effects associated with inhalable particulates and ozone. These data are then used to estimate reductions in health effects associated with two emission reduction scenarios.

Ozone is considered to be the most damaging of all atmospheric pollutants affecting crops, forest, ornamentals and natural vegetation. The effects have been recognized since the late 1950s and research continues today to refine the exposure and response relationship. Section D outlines the historical and recent developments in assessing the ozone impacts on vegetation.

Ambient air monitoring of ozone, nitrogen oxides, volatile organic compounds and inhalable particulate are conducted by the Ontario Ministry of Environment and Energy. Emission inventories are also compiled to track the release of nitrogen oxides, volatile organic compounds and inhalable particulates into the atmosphere. Section E summarizes the information on spatial variations in ambient levels, trends in ambient concentrations and emission, and relative contributions from various sources and sectors.

Smog formation is influenced by a variety of factors including atmospheric chemistry, meteorology, and magnitude and spatial distribution of emission sources. The formation mechanisms are extremely complex; therefore, atmospheric photochemical models are applied to derive emission reduction targets needed to resolve the ozone problems in each region. Section F describes the latest developments in photochemical modelling for the Ontario region. The modelling results are then used to derive expected reductions in ozone levels under the various proposed smog reduction scenarios.

Emissions of nitrogen oxides and volatile organic compounds have been declining since 1985. This decline is due to a combination of economic slow down and actions to reduce these pollutants. Section G summaries the existing commitments from the various emission source sectors. This section also explores on-going activities that are expected to provide further readily available reductions. Emissions are then forecasted up to the year 2015, taking into consideration the potential for economic growth. The forecasted values are then used to determine the NO_x and VOC reductions needed to counter the effects of growth in emissions.

Benefits-cost analysis is an analytical tool that can be used to evaluate public policy questions such as smog reduction. Section H provides estimated values of health benefits due to various smog reduction scenarios. Control cost data are not available presently to complete a full benefits-cost analysis; therefore, an incremental benefit-cost framework is presented which can be applied for this type of analysis.

Overview of Reduction Scenarios

Two reduction scenarios were examined in "Toward a Smog Plan for Ontario". The details on the emission reductions, baseline emissions forecast, ambient air quality improvements, health gains and monetary value of benefits are presented in various sections, for these two scenarios. A brief overview is provided here to guide the reader to the information in the various sections.

The two reduction scenarios of the discussion paper are identified as:

1) existing and readily available reductions; and

2) 45% reductions from 1990 nitrogen oxide and volatile organic compound emissions.

Details on the specific reductions and forecasted emissions under these scenarios are presented in Section G (subsections 3, 4, 5 and 6). All the benefits were examined relative to a base case which assumes no additional controls after 1990, referred to as "Unreduced Emission - Growth only from 1990". The base case emissions forecast is presented in Section G (subsection 2).

Emission reductions are then used to estimate improvements in ambient air quality (reduction in ozone concentrations). These improvements are derived from results of existing photochemical modelling studies. Details on the derivation of the ozone concentration reductions are presented in Section F (subsection 2).

Nitrogen oxides and volatile organic compounds react in the atmosphere to form secondary particulates. Therefore, reductions in nitrogen oxides and volatile organic compound emissions are expected to result in decreases in secondary formation of inhalable particulates. The estimated reductions in inhalable particulate concentrations due to decreases in secondary particulate formation is presented in Section F (subsection 3).

The estimated reductions in ozone, inhalable particulate concentrations are subsequently combined with concentration response functions to estimate and quantify the public health gains (e.g., reduction in health effects). Details of the estimated health gains are summarized in Section C (subsection 3).

The monetary values of the public health gains are estimated using various methods and techniques (e.g., willingness to pay, cost of illness). Details of the estimated monetary values of reduced health effects are presented in Section H (subsection 4).

SECTION A

INTERGOVERNMENTAL ACTIVITIES

SECTION A

INTERGOVERNMENTAL ACTIVITIES

The Ministry of Environment and Energy is initiating development of an Ontario Smog Management Plan which will be a key component of a new National Smog Strategy that is expected to be completed by 1997. The following notes summarize provincial, national and international activities in this field. They are not a complete description of all initiatives but are intended to provide a context for the development of the Ontario smog plan.

1. 1990 CCME NO_x/VOC MANAGEMENT PLAN

In 1990, the Canadian Council of Ministers of the Environment (CCME) adopted a Management Plan to reduce NO_x and VOC emissions in Canada. It was composed of three phases. First phase consisted of: 1) develop and implement national and regional control initiatives to reduce NO_x and VOC emissions from a broad cross-section of industries and transportation sources; 2) further develop scientific knowledge on inventories, health and vegetation effects, ambient air monitoring, and modelling of future control scenarios, and 3) conduct sectoral studies to better quantify their emission problems and potential solutions. This phase also involved a public education effort to help the public make judicious environmental choices in their daily behaviour. The second phase was intended to define additional regional control measures to reduce emissions to meet the Canadian 82 ppb ambient air quality objective by 2005. If exceedances of the air quality objective still occurred after phase II, a third phase addressing specific areas and targeted measures would be developed and implemented.

The objectives of Phase 1 of the 1990 CCME Plan were as follows:

- Implement national prevention measures for new sources of NO_x and VOC built across Canada and apply retrofits through a regional remedial program to existing sources in high ozone areas where local emissions contribute significantly to violations of the maximum acceptable National Ambient Air Quality Objective of 82 ppb ozone for one hour;

- Develop and deliver a public education program which will help people become aware of the smog problem and help them make judicious decisions on lifestyle changes that would contribute to emission reductions, particularly with respect to the use of the automobile, alternate transportation modes, energy efficiency, and the use of consumer products containing solvents;

- Undertake a broadly focussed air pollution research program that would characterize global, international and local ambient air quality problems and help determine the types of control measures and human actions that will lead to a consistent, uniform

and effective resolution of local air pollution problems in Canada, while doing our part to resolve transboundary issues;

- Recognize the linkages with other air issues such as global warming, air toxics, acid rain and ozone depleting substances in an effort to produce solutions that positively contribute to resolve those issues (e.g. NO_x reduction related to energy efficiency reduces CO_2 and fine particulates, VOC may contain toxic substances);

- Recognize that implementation of control measures at the earliest opportunity at existing sources will provide the greatest and most immediate benefit to air quality, whereas implementation of the national prevention program is mainly a longer term effort.

At present, many **national and regional initiatives** have been developed and some have been implemented. Some of these initiatives such as vehicle standards, consumer products formulation, gasoline vapour pressure reduction, NO_x emissions from power plants, and public education are in place. Other alternative NO_x and VOC emission control measures have also been implemented by various provinces. However, a number of national initiatives and control measures identified in Phase 1 of the Plan have not been implemented yet. At present, the expected reductions are not in line with the emission reductions required to meet the 82 ppb nonexceedance objective. In summary, as of January 1996, 16 of 31 prevention measures in Phase 1 have been completed; the rest are in progress or have been addressed by an alternative approach.

The **science program,** which will provide the basis for development of next steps in the renewed smog management plans, is progressing toward a mid 1996 assessment.

Seven scientific work group reports which form the basis of the assessment content are nearing completion. The planned delivery date for the work group reports was the end of December 1995 however due to certain constraints work is ongoing and most of the peer review work will continue through the spring of 1996. The drafting of the assessment is proceeding in parallel with the finalization of the work group reports. Writing of the assessment is the responsibility of the NO_x/VOC Science Assessment and Policy Integration Group of Atmospheric Environment Service (Environment Canada).

Although final results are not yet available from any of the work groups, work to date has succeeded in making significant contributions to furthering the understanding of all aspects of the Canadian ground level ozone issue. Highlights of the progress are provided, by work group.

1. Ambient Data Analysis:

- the report provides the first comprehensive analysis of ground level ozone in Canada for the period 1980-93. It includes characteristics of ozone concentrations, trends, frequency distributions and regional variations in concentrations and trends. This work is supported by journal publications which confirm the need for a regional approach for reducing precursor emissions to control ozone.
- the draft report which also includes ozone climatology in Canada, ozone precursor analysis, ozone precursor trend relationships and long range transport, is currently being peer reviewed by international scientific experts.

2. Emission Inventory:

- the report includes the completed 1990 emission inventory of common air pollutants for Canada.
- the group was responsible for initiation of the gridding project to prepare the 1990 inventory for use in the atmospheric models.
- the draft work group report, which defines the 1990 inventory, provides forecasts and trends for NO_x and VOC emissions, explains the link between the inventories and models and attempts to define the uncertainties in the NO_x and VOC inventories, is near completion.

3. Ambient Air Monitoring:

- the work group has prepared a draft national monitoring guidelines document for ozone, NO_x and VOC which defines monitoring and data quality objectives, guidelines for station siting and operation, measurement methods, meteorological measurements and data management procedures as the foundation of the national network design.
- the work group is near completion of a draft monitoring network implementation report which includes an assessment of current monitoring network capability, a review of site classification requirements against established sites, identifies deficiencies and provides an implementation plan recommending enhancements of existing sites and establishing a few new sites to fill spatial gaps.

4. Lower Fraser Valley (LFV) Modelling:

- the report provides validation of appropriate regional models for application of selected NO_x and VOC control scenarios.

- the report presents new information, largely based on the Pacific '93 field program, with considerably improved understanding of the meteorology and chemistry of ozone episodes in the LFV.
- the report describes the regional characteristics of the LFV and describes the model development and evaluates the impact of emission change scenarios using a 1985 base case.

5. Windsor Quebec Corridor/Southern Atlantic Region (WQC/SAR) Modelling:

    - the report provides a comprehensive evaluation of a number of relevant meteorological and chemical models against the ambient data collected during the Eularian Model Evaluation Field Study I (August 1988).
    - the report includes application of the selected models yielding preliminary results for NO_x and VOC emission control scenarios.
    - the draft report will summarize the results of the evaluation and make recommendations on further work on the model systems and scenario applications.

6. Vegetation Objective:

    - the work group has completed a review of the US National Crop Loss Assessment Network data and the European Open Top Chamber Program.
    - agreement has been reached in the work group that both mid-range (40-80ppb) and peak concentrations adversely impact vegetation.
    - work is nearing completion on a recommendation for an appropriate form and level of an objective to protect Canadian vegetation, including a recommendation on degrees of risk associated with levels of protection.

7. Health Objective:

    - the draft report, including science evaluations of animal toxicity, clinical studies, epidemiology and exposure assessment is near completion.
    - dose-response curves developed for lung decrement and respiratory hospital admissions are presented in the report as significant health end points which support that there is no scientific evidence of a clear threshold for health response to ground level ozone.
    - the report will provide a recommendation on an appropriate form and level for a Canadian ozone objective to protect human health, including associated risk characterization.

2. NATIONAL AIR ISSUES CO-ORDINATING MECHANISM

The National Air Issues Coordinating Mechanism (NAICM) was established under the provisions of the Comprehensive Air Quality Management Framework for Canada, which was endorsed by environment and energy ministers in 1993. The impetus for the Framework and NAICM was the necessity for better federal-provincial coordination for responding to air quality issues, the desire of energy ministries to be at the table since many air issues are reflected in energy policy, and the need to integrate policy development on air issues.

The NAICM consists of a Steering Committee (NAISC) comprised of federal and provincial/territorial deputy ministers of energy and environment, and a Coordinating Committee (NAICC) of assistant deputy ministers and senior officials. The NAICC has a number of issue-specific and cross-cutting Task Groups comprised of both government and non-government participants. The NAICC itself also consults regularly with a group of non-government stakeholders.

In 1995/96, the Steering Committee is co-chaired by Natural Resources Canada and Ontario Ministry of Environment and Energy (MOEE). NAICC is co-chaired by Environment Canada and Ontario MOEE.

Responsibilities of the NAICC include the following:

1. Implementing the Comprehensive Air Quality Management Framework Agreement.

2. Developing coordinated air issue management plans and strategies as directed by the NAISC.

3. Providing advice to the federal government on negotiating positions and strategies for international air quality agreements and on national issues.

4. Improving the coordination and cooperation on scientific, technological and economic activities in order to improve air quality and atmospheric issue management in Canada and integration of actions on air issues.

5. Establishing processes for effective national stakeholder consultations with respect to the above noted items.

6. Establishing supporting task groups as necessary to fulfil these responsibilities.

7. Tracking the progress in achieving emission reduction targets and other actions established in regional and national strategies and international agreements.

Substantive results to date of the National Air Issues Co-ordinating Mechanism include the following:

Climate Change	Development of the National Action Program on Climate Change, the Voluntary Challenge and Registry Program and the economic analysis of measures to reduce emissions.
Stratospheric Ozone	Development of measures to strengthen Canada's ozone layer protection program.
Smog	Development of the strategic directions for preparation of a National Smog Strategy.
Acidifying Emissions	Draft elements of a National SO_2 Reduction Strategy have been prepared by the Acidifying Emissions Task Group for further development in 1996.
Hazardous Air Pollutants	The Hazardous Air Polluntants Task Group is responding to priorities identified at the April 1995 stakeholder workshop for developing both a domestic program and national position for international action.
Inventories	Completion of a National Consensus Base Case Forecast for NO_x, VOC and SO_2 emissions to 2015, by the National Emissions Inventory and Projections Task Group.

3. NATIONAL AMBIENT AIR QUALITY OBJECTIVES

The establishment of National Ambient Air Quality Objectives (NAAQOs) is the responsibility of the Working Group on Air Quality Objectives and Guidelines (WGAQOG), a federal-provincial working group. This working group reports to the CEPA/FPAC (ie. Canadian Environmental Protection Act/ Federal Provincial Advisory Committee) parent committee, which has members from Environment Canada and several provincial Environment Ministries. The WGAQOG itself has members from all provincial Environmental and Health Ministries, as well as, Environment and Health Canada and is co-chaired by one Federal and one Provincial member. There are linkages between NAICC and CEPA/FPAC to ensure input to the priorities in NAAQO development.

The national ambient air quality objectives, once developed, are directly adopted or adopted with modification, reflecting local conditions, to become provincial ambient air quality guidelines or standards. In particular, development of NAAQO for **PM-10**, one of the main components of smog, is in the final stages of development. Also, the recommendations on **ozone**, from the Health and Vegetation Objective multistakeholder working groups, under the previously mentioned '**science program**' of the CCME (see section 1) will be forwarded to the WGAQOG to be developed into an ozone NAAQO.

4. REVIEW OF PROGRESS OF THE 1990 CCME MANAGEMENT PLAN

At their first joint meeting, in November 1993, under the National Air Issues Co-ordinating Mechanism, Environment and Energy Ministers requested advice on whether to recommend that Canada ratify the 1991 VOC Protocol under the United Nations Economic Commission for Europe (UN ECE) Convention on Long-Range Transboundary Air Pollution (LRTAP). The National Air Issues Steering Committee (NAISC), the body charged with providing this advice, subsequently requested that the status report be more complete and deal not only with Canada's ability to meet commitments in the VOC Protocol but also provide advice to Ministers on the overall implementation of the CCME NO_x/VOC Management Plan.

The progress report was submitted to the Ministers at their next annual joint meeting in November 1994 at Bathurst (N.B.). The following notes are extracts from drafts of this report:

> "The Phase I NO_x/VOC Management Plan was endorsed in principle by Environment Ministers in 1990. Considerable progress has been made in implementing the Plan. In particular the preventative measures of the Plan which are mostly implemented through the provinces' existing permitting process, have progressed satisfactorily. However, a larger number of initiatives related to the remediation portion of the Plan have not proceeded as quickly as envisaged.
>
> It has taken time for all jurisdictions to secure resourcing and for key provinces to develop regional ozone management strategies. The latter has been difficult in the Windsor-Quebec corridor (WQC) and in the Southern Atlantic region (SAR) due to the large effect transboundary pollutants have on the problem and on the impact of local remediation measures. A general economic downturn since the Plan was issued, coupled with competing priorities, stretched the timelines for development of response programs. In addition, new technologies, products, priorities and programs emerged during the intervening four years.
>
> At the same time, the growing attention devoted to other types of air pollutants confirmed the Smog Plan perspective that a large proportion of these, as well as the smog causing pollutants, were significantly related. That confirmation, accompanied by the desire to use resources as effectively as possible, led the Ministers to direct that air pollutants be dealt with in an integrated and holistic manner. That revised approach, as well as the difficulties inherent in having individual federal-provincial agreements on the implementation of the Plan caused the creation of an umbrella agreement for managing air issues nationally, called A Comprehensive Air Quality Management Framework for Canada, which was endorsed by Environment and Energy Ministers in late 1993. Progress in implementing this Plan must be assessed in this context.

The NO_x/VOC Management Plan contains significant commitments to energy efficiency improvements. These commitments are being re-examined in light of their potential to provide additional benefits in view of Canada's new international and domestic commitments to control emissions of other pollutants.

The progress report went on to conclude that Canada must redefine its approach to NO_x/VOC management in order to:

- Make progress towards the original objectives of reducing ozone concentrations to 82ppb.
- Meet the additional objective of dealing with air pollutants in an integrated and holistic manner.
- Meet Canada's international commitments in terms of national and regional NO_x and VOC emissions reporting and reductions.
- Integrate and respond to the evolving knowledge base in regards to the -
    - health effects of ozone
    - NO_x contribution to acid deposition
    - contribution of smog components to the formation of particulates having damaging health effects
- Ensure that the delivery of the initiatives will occur.
- Integrate economic instruments in the suite of tools available as control instruments
- Develop a strategy to deal with the transboundary flow of ozone precursors into Canada.

Ministers responded to the progress review and recommendations by calling for the preparation of a renewed National Smog Strategy. The new national plan was expected to build on the Phase I achievements of the 1990 CCME plan and to incorporate unfinished elements of that plan. The originally projected Phase II and Phase III of the 1990 CCME plan were to be rejected in favour of the new plan.

5. NATIONAL SMOG STRATEGY

To address the Ministers November 1994 directive, the National Air Issues Co-ordinating Committee (NAICC) formed a Smog Task Group, co-chaired by Environment Canada and

Ontario MOEE, with the immediate task of assembling a workplan for development of the new National Smog Strategy. The workplan was endorsed by Environment Ministers in spring 1995 and called for completion of the new national plan by 1997.

A framework for the new national plan was tabled at the November 1995 joint meeting of Environment and Energy Ministers in Edmonton. The proposed National Smog Strategy is to consist of:

(a) A **National Smog Management Plan (NSMP)** with measures best taken at the national level. These are mostly initiatives already in progress resulting from existing consultative mechanisms and include components such as most of the preventative measures in the 1990 NO_x/VOC Management Plan (Phase I), the Cleaner Vehicles and Fuels initiative; public education on transportation and other lifestyle issues, and other initiatives on products, processes and on energy efficiency.

(b) Four **Regional Smog Management Plans (RSMP's)** - one each for the Ontario and Quebec portions of the Windsor-Quebec Corridor, one for the Lower Fraser Valley of B.C., and one for the Southern Atlantic Region. These are to be jointly developed and implemented by the provinces involved and the federal government, building upon the regional remedial programs in Phase I.

(c) The scope of smog management will be expanded to address other pollutants such as inhalable particulate matter.

6. SMOG MANAGEMENT ACTIVITY IN OTHER PROVINCES

While smog (ground-level ozone and particulates) is an air pollution problem in virtually all large urban centres in Canada, the most significant effects are felt in three regions:

- Lower Fraser Valley of British Columbia;
- Windsor-Quebec Corridor of Ontario and Quebec;
- Southern Atlantic Region of New Brunswick and Nova Scotia.

The current effort to initiate development of an Ontario Smog Management Plan is intended to address the Ontario portion of the Windsor-Quebec Corridor.

In **Quebec**, several ozone management measures for the Quebec portion of the Windsor-Quebec Corridor have been implemented under the current CCME NO_x/VOC Management Plan. Provincial representatives have expressed interest in developing a renewed Regional Smog Management Plan. The initial focus is expected to be on transportation and

transboundary components of the problem. The form of the Quebec regional plan, and its results, will rely in part on what is developed for the Ontario plan.

In the **Southern Atlantic Region**, high ground-level ozone levels continue to occur mainly due to transboundary inflows. An estimated 80% of the regions ground-level ozone problem is understood to have originated in the north-eastern US states. Monitoring work is conducted co-operatively by federal and provincial departments and the state of Maine.

Emission prevention and new-source control programs are under consideration or development by Nova Scotia and New Brunswick. These provinces are also trying to strengthen linkages with US regional groups such as the Northeast States for Co-ordinated Air Use Management (NESCAUM) and the Ozone Transport Commission (OTC) of the northeastern states. A major conference sponsored by the New England Governors and Eastern Canadian Premiers was held in St. John in April 1996 to share solutions to the smog and associated problems.

In the **Lower Fraser Valley of British Columbia** activities related to smog management and interest in the inhalable particulates issue are more advanced than in the other regions of Canada. For example,

- Under the 1990 CCME NO_x/VOC Plan, a draft federal-provincial agreement to address regional smog problems was negotiated in 1994 but was not completed. Agreement was not reached because of resource constraints, and an inability to address energy efficiency. However, the main elements of the Regional Smog Management Plan for the Lower Fraser Valley (LFV) are well advanced. Smog is a component of a broader Air Quality Management Plan for the Greater Vancouver Regional District (GVRD) and deals with a range of pollutants such as inhalable particulates, ozone, and hazardous air pollutants.

- The Lower Fraser Valley already has developed a coordinated program with regional districts, Washington State, and federal and provincial governments in the LFV Air Quality Coordinating Committee.

- A major public education and communications program called "Go Green" is in place for all of B.C. with a special focus in the LFV. Initiatives on transportation include: expansion of HOV (high occupancy vehicle) lanes, cycling paths and light-rail mass transit.

- An air quality index-based public alert program is in place for exceedences of any air quality parameter including ozone, NO_x, and PM10.

- B.C. has initiated a program to address inhalable particulate matter including research, emissions inventories and regulatory controls.

- The province's Air Care Program operates in the LFV and is being tightened and expanded to include heavy-duty on-road vehicles.

- The federal government cooperates with the province and the GVRD, observing at or participating in the management committees for the GRVD Plan and for implementing the B.C.-Washington Memorandum of Understanding on Air Quality.

- In December 1995, British Columbia announced a strict vehicle and fuels emissions program which essentially puts into effect the measures contained in the Cleaner Vehicles and Fuels initiatives endorsed by CCME Ministers at their October, 1995 meeting. The Clean Vehicles and Fuels Program is taking action on five fronts:

    1. Reducing emissions from existing vehicles;

    2. Encouraging the availability and use of cleaner new vehicles;

    3. Reducing emissions from existing fuels;

    4. Encouraging the availability and use of cleaner alternative fuels; and

    5. Improving gasoline distribution and refuelling systems.

The B.C. Ministry of Environment considers that emission and fuel efficiency standards for new vehicles, and changes to fuel formulations are the most effective ways of reducing emissions from new motor vehicles and that programs like AirCare ensure that benefits of such standards are maintained over the life of the vehicle.

AirCare is the provincial vehicle emissions inspection-and-maintenance program that has been in place in the LFV since 1992. The program, developed jointly by the province, the GVRD and Environment Canada requires that all light-duty vehicles pass an annual emissions inspection as a condition of licensing.

The GVRD Air Quality Management Plan projects that this program has the largest single impact of any measure in reducing vehicle emissions from the existing fleet.

The current emission test-levels are intended to fail vehicles which emit much more than when the vehicles were new. In some cases the allowable emission levels are five to ten times higher than the original manufactured standard; the test-levels were set high to allow for normal deterioration.

7. CANADA US AIR QUALITY AGREEMENT

Canada and the United States signed an Air Quality Agreement on March 13, 1991 to establish a practical and effective instrument to address shared concerns regarding transboundary air pollution. Initially, the focus was on acid rain; however, recent discussions also included ground level ozone issues.

The Agreement provides a framework for:

- the establishment of specific objectives for emissions limitations or reductions of air pollutants and adoption of the necessary programs and other measures to implement such specific objectives;

- undertaking environmental impact assessment, prior notification, and, as appropriate, mitigation measures;

- carrying out coordinated or cooperative scientific and technical activities, and economic research and exchanging information;

- establishing institutional arrangements;

- reviewing and assessing progress, consulting, addressing issues of concern, and settling disputes.

A binational Air Quality Committee was established to assist in the implementation of the Agreement and to review progress made. The committee is co-chaired by Environment Canada and U.S. Department of State. There are eight other Canadian members and six U.S. members. Four provinces are represented (Ontario , Quebec, Saskatchewan and Newfoundland) and the rest of the Canadian members are from the various federal departments.

Article X of the Agreement stipulates that the Parties shall conduct a comprehensive review and assessment of this Agreement, and its implementation, during the fifth year after its entry into force and every five years thereafter, unless otherwise agreed. The first fifth year review took place between March, 1995 and March, 1996. The governments plan to publish their five-year review in the 1996 Progress Report on the Air Quality Agreement.

As part of the review exercise, the governments requested the International Joint Commission to solicit public input. The IJC held public hearings in Ottawa (November 1995) and Washington DC (December, 1995) and, in December, released a synthesis of comments received. This summary highlighted the need for better co-ordination of targets and measures in neighbouring jurisdictions (e.g. Ontario and US States) and the need to approach air pollution issues on a regional air-shed basis.

A number of the comments received by the IJC are especially pertinent to current efforts concerning the Ontario Smog Management Plan. For example,

- The suggestion was made that the Agreement should become a framework for action to ensure that the internation border does not become an excuse for states or provinces to avoid reasonable obligations to their neighbouring jurisdiction. Means should be explored through which adjacent Canadian jurisdictions have the same recognition as adjoining states under the Clean Air Act provisions relating to adjoining states.

- It was suggested that more than 50% of the ground level ozone in Ontario comes from emissions in the United States and even if all of the sources of precursors are eliminated in Ontario, the region would still have an ozone problem. It was also pointed out that United States legislation does not require air quality State Implementations Plans under the Clean Air Act to consider international transboundary effects, thus resulting in unequitable treatment for a downwind province as opposed to a neighbouring state.

- It was suggested that citizens on both sides of the border deserve comparable protection and that Governments should work cooperatively to establish regionally harmonized, uniformly enforced standards that protect human health. Specifically, the call for harmonized ozone standards was seen as being a realistic goal, since both countries are currently reviewing their standards.

- As a starting point to resolve this discrepancy across the international boundary, it was suggested that the two federal governments take all necessary steps to achieve harmonization of their ozone standards/objectives. This harmonization should be established at a level comparable to Ontario's current objective or at a more stringent level. It was also recommended that the Agreement outline an approach for Canada and the United States to achieve this harmonized ozone objective, that control strategies be developed on the basis of entire airsheds, rather that being constrained by international boundaries, and that the Agreement be the mechanism for implementation.

8. U.S. EMISSION MANAGEMENT ACTIVITY

Several regional airshed initiatives focussing on the smog problem are underway in the United States. They are mainly sponsored by the US Environmental Protection Agency, and could have important implications and benefits for Ontario.

8.1 Ozone Transport Commission (OTC)

The Ozone Transport Commission was created by the US Clean Air Act Amendments of 1990 to coordinate the regional development of control plans for ground level ozone in the Northeast and Mid-Atlantic States. Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia are represented on the OTC.

In 1994, the States of the OTC completed a memorandum of understanding on development of a regional strategy concerning the control of stationary source NO_x emissions. In particular, the States of the OTC agreed to prepare regulations that require subject sources to reduce NO_x emissions by 55-75% from base year (1990) levels by 2003.

The OTC also determined and recommended to the US EPA that a regional Low Emissions Vehicle program would be necessary to bring the OTC region into attainment by the dates stipulated in the US Clean Air Act.

Future OTC efforts are expected to be absorbed into a broader regional initiative called OTAG (see below).

8.2 Regional Ozone Study Area (ROSA)

As the result of a 1994 meeting between Environment Canada Minister Copps and (US EPA Administrator), Carol Browner a Regional Ozone Study Area (ROSA) was proposed as a joint Canada-US effort to co-ordinate a study of control scenarios for the precursors of ozone in southern Ontario and states to the north and southwest. The states included New York, Pennsylvania, West Virginia, Kentucky, Ohio, Indiana, Illinois and the southern part of Michigan.

The project was to concentrate initially on NO_x control scenarios for stationary sources using an approach similar to the Ozone Transport Commission. Some preliminary modelling work was undertaken. For example, the impact of controls proposed under ROSA was assessed in model runs carried out by the US EPA.

From Ontario's perspective, a weakness of the ROSA proposal was the specific exclusion of Chicago and much of Michigan. Under appropriate meteorological conditions, both excluded areas can have an impact on Southern Ontario.

The future of the ROSA initiative is uncertain. In the U.S., future activities are likely to be absorbed in the broader OTAG initiative (see below) to which Canada/Ontario is not formally linked.

8.3 Ozone Transport Assessment Group (OTAG)

The OTAG process is a comprehensive effort of the 37 States east of the Mississippi River to resolve the pervasive regional smog problem in the Eastern U.S. Aggressive actions such as strict retrofit NO_x standards for power plants, are being seriously evaluated. To date, initial reduction strategies have been developed, atmospheric modelling is now beginning, and by September, 1996, a recommendation to the OTAG Policy Group on an emission reduction strategy is expected. The OTC efforts and preliminary ROSA efforts have essentially been absorbed within the broader OTAG effort. The potential exists to coordinate the Ontario and Quebec regional smog plans with OTAG plan elements in adjacent regions or States. However, a mechanism for such co-ordination is not yet under active consideration.

OTAG is sponsored by the US EPA and is managed by State Environmental Commissioners through a Policy Group and a large complex substructure of committees and working-groups. Costs of the process (in the millions of dollars) and output of the working groups are correspondingly large.

Key objectives of the OTAG process may be summarised as follows:

- Full implementation of Clean Air Act through 2007
- Region-wide NO_x reductions from utility and other industrial sources
- Mobile source approach
    - 49 State Low Emission Vehicle Program
    - Reformulated gasoline
    - Inspection/Maintenance Programs
- Combined mobile and stationary source controls
- Application of controls according to particular requirements of sub-regions
- Extension of Nonattainment area requirements.

8.4 US Ozone and Particulate Standards

The US EPA continues its review of its ambient air quality standard for ozone (120 ppb, 1 hour), which is about a 50% higher than the Canadian one-hour objective 82 ppb. A decision is expected by June 1996 on a new 8-hour ambient standard for ozone in the 70 to 90 ppb range. The 90 level would not represent much of a change from the current 120ppb one-hour figure but an 8-hour limit of 70ppb would approximate the Canadian objective.

The EPA is also under a court-ordered schedule for review of the national standard for particulate matter and a decision is expected by mid 1996. Consideration is being given to the establishment of a new 24 hour and annual fine particle standard to replace the existing 24 hour PM-10 standard. The existing annual PM-10 standard is likely to be retained.

9. UNECE PROTOCOL ON NITROGEN OXIDES

In 1979 Canada signed the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (LRTAP Convention). Since then Canada has signed four protocols under this convention: the First Sulphur Protocol (1985), the First Nitrogen Protocol (1988), the Volatile Organic Compound Protocol (1991) and the Second Sulphur Protocol (1994). To date Canada has ratified only two of these, the First Sulphur and First Nitrogen Protocols.

The First Nitrogen Protocol committed Canada to stabilize nitrogen dioxide emissions at 1987 levels by 1994, which was achieved. Other obligations include: apply national emissions standards to new mobile and stationary sources, introduce pollution control measures for major existing stationary sources, and commence negotiations on further steps to reduce emissions of nitrogen oxides no later than six months after the date of entry into force of the present protocol, which occurred in 1991. The final basic obligation is that the parties shall cooperate to establish: critical loads; reductions in emissions required to achieve agreed-upon objectives based on critical loads; and measures and a timetable for achieving such reductions by January 1, 1996.

There was an agreement by the Executive Body to the LRTAP Convention and by the subsidiary Working Group on Strategies, that they should explore the feasibility of making the Second Nitrogen Protocol a multi-pollutant, multi-effect protocol, and seek to eliminate or reduce environmental damage caused by eutrophication, acidification and ground level ozone by controlling emissions of nitrogen oxides, ammonia, volatile organic compounds and sulphur dioxide.

Under the direction of the Working Group on Strategies, two of the scientific groups under the Convention (specifically the Task Force on Integrated Assessment Modelling and the Working Group on Effects) have made considerable progress in evaluating multi-pollutant emission reduction schemes for Europe that will be required to resolve the three issues.

In February 1996, the Executive Body directed the Working Group on Strategies to prepare a draft protocol, using a multi-pollutant approach, and addressing photochemical pollution, acidification, and eutrophication. The Working Group was to aim at finalizing negotiations by the end of 1997.

For its part, in February 1996, the Working Group considered a proposal on possible elements and a structure for a protocol on the further reduction of emissions of nitrogen compounds and VOC's submitted by a group of five European countries (including Germany). **It should be noted that the ground-level ozone standard advocated by this group was equivalent to 55 ppb.**

As the province that, potentially, could have to address the greatest impact from these international commitments, Ontario monitors activities of the UNECE closely. Environment Canada holds regular multistakeholder consultations prior to these international consultations. The ramifications of such activities will need to be addressed in the Ontario Smog Plan.

SECTION B

LINKAGE OF SMOG TO OTHER ENVIRONMENTAL ISSUES

SECTION B
LINKAGE OF SMOG TO OTHER ENVIRONMENTAL ISSUES

Smog is not an isolated environmental issue. It is closely linked to many other environmental issues in terms of pollutants and source types. These environmental issues are: acid rain, climate change, depletion of ozone layer (stratospheric ozone), quality of life (noise, odour, taste, discoloration and soiling), and airborne toxics.

1. Common Pollutants

Table B.1 summarizes the common pollutants and/or precursors associated with the various environmental issues.

Ozone (O_3), in the troposphere, is a key component of smog in the summer time. In the stratosphere, ozone has a protecting effect, shielding the sun's harmful ultraviolet radiation from reaching the earth's surface. When stratospheric ozone is destroyed by chlorine and bromine atoms photo-dissociated from chlorine- and bromine-containing compounds, such as chlorofluorocarbons (CFCs), substituted CFCs, HCFC, halons, the so-called ozone hole is created in the stratosphere. Ozone is also a greenhouse gas. Although the impact of tropospheric ozone on global warming is not well-defined, on a molecule by molecule basis, O_3 is about 2,000 times more potent than carbon dioxide (CO_2) as a greenhouse gas. Some may consider ozone as a toxic compound because of its many health end points at low levels.

Another major component of smog is particulate with an aerodynamic diameter equal to or less than 10 microns, which is commonly called inhalable particulate, or PM_{10}. This component of smog is especially important in the wintertime when photochemistry is not prevalent to form ground level O_3. Those particles not greater than 2.5 microns are called fine or respirable particulate, or $PM_{2.5}$ in short. Both PM_{10} and $PM_{2.5}$ can be produced as primary pollutants from industrial and combustion processes and fugitive emissions such as road dust. They can also be formed as secondary pollutants when pollutant gases, such as nitrogen oxides (NO_x, which is the sum of NO_2 and NO), sulphur dioxide (SO_2), and volatile organic compounds (VOCs), react in the atmosphere to form acids and aerosols. Particulate also contributes to soiling and visibility problems and may be characterized by toxic properties. Acidic components contribute to acid rain.

Nitrogen oxides and VOCs, in the presence of sunlight, react to form ozone. They are therefore precursors of ground level O_3. As noted earlier, these precursors also lead to the formation of nitric acid, nitrate aerosols and organic aerosols, which are less than 2.5 microns in size. Many of the common VOCs are odorous (e.g., aldehydes) or toxic, with some known to be human carcinogens (e.g., benzene).

NO_x (as a precursor to ground level O_3 and secondary nitrate aerosol) and SO_2 (as a precursor to sulphate aerosol) are also acid gases, which cause acid rain (wet and dry acid deposition).

Because constituents of smog are also linked to these other environmental issues, reduction of smog precursor emissions will reduce the extent of many environmental problems as well.

2. Common Sources/Source Sectors

Table B.2 lists the emission source categories/sectors reflecting their geographic scales, namely, local (industry, transportation, power generation, household, agriculture and waste-related), regional (tranbsboundary) and global scales. Information on the pollutants generated by the different source sectors can be found in Table B.3. As well, this table lists ranked priority of each issue with respect to its impacts on ecological and human health, based on a process used in the Ministry's Environmental Sciences and Standards Division.

Smog is linked to regional transport of air pollutants. Without reduction of transboundary emissions from the United States, Ontario's smog problem will not be adequately resolved. There are bilateral mechanisms (such as the Canada-US Air Quality Agreement) already in place to deal with acid rain and they can be expanded to address the smog problem.

Sectoral data associated with local sources in Ontario provides information on the relative magnitudes of the various source emissions and provides some guidance to identify and target sources for abatement action. It is clear that many of the smog sources also contribute to negative effects associated with many other environmental issues. These sources relate to industry, agriculture, waste management and consumer products.

One of the pros in choosing abatement action as a remedial measure is the potential to improve a number of environmental impacts in a source sector type, e.g., reducing transportation-related emissions will not only reduce smog, it will also reduce the acid rain, climate change, ozone layer depletion and soiling and alleviate toxics exposure. With source process and technology, emission and cost information, cost-effectiveness can be determined.

3. Conclusion

The smog issue is linked to many other environmental issues. This means that reductions in smog precursor emissions will also generate benefits concerning other environmental problems. Estimates of the benefits associated with smog reductions alone will underestimate the quantity and value of all of the benefits that may be achieved by specific control programs.

This very fact challenges us to look for remedial actions which would maximize the reduction in pollutant types and quantity as well as multi- environmental issue benefits.

TABLE B.1
LINKAGE BETWEEN SMOG AND OTHER RELATED ENVIRONMENTAL ISSUES AND POLLUTANTS

ISSUE/POLLUTANTS	O_3	NOx	VOCs	SO_2	PARTICULATE	ACID AEROSOL
Smog: ground level ozone	x	x	x			
Smog: PM_{10} and $PM_{2.5}$		x	x	x	x	x
Acid rain		x		x	x	x
Climate change	(x)					x
Depletion of ozone layer						
Noise, odour, taste, discoloration, soiling			x		x	x
Airborne toxics	(x)		x		x	x

(x) = not well-defined

TABLE B.2
SMOG AND OTHER RELATED ENVIRONMENTAL ISSUES AND SOURCE SECTORS

ISSUE/SECTORS	IND^{Y}	TRANSP^{N}	POWER	HOUSE	AGRI	WASTE	TRANSB^{Y}	GLOBAL
Smog: ground level ozone	x	x	x	x	x	x	x	
Smog: PM_{10} and $PM_{2.5}$	x	x	x	x	x	x	x	
Acid rain	x	x	x	x			x	
Climate change	x	x	x	x	x	x		x
Depletion of ozone layer	x	x		x	x			x
Noise, odour, taste, discoloration, soiling	x	x	x	x	x	x		
Airborne toxics	x	x	x	x	x	x	x	x

IND^{Y}=INDUSTRIAL SECTOR; TRNASP^{N}=TRANSPORTATION SECTOR; POWER=UTILITIES; HOUSE=HOUSEHOLD USES; AGRI=AGRICULTURAL SECTOR; WASTE=WASTE MANAGEMENT RELATED PRACTICES; TRANSB^{Y}=TRNASBOUNDARY POLLUTION; GLOBAL=GLOBAL CONTRIBUTION

TABLE B.3
CHARACTERIZATION OF ENVIRONMENTAL ISSUES

ISSUE	POLLUTANTS	SOURCE SECTOR	DIRECT HEALTH EFFECTS	
			ECOLOGICAL	HUMAN
SMOG: Ground level ozone	**O_3, NO_x, VOCs**	**Industry** (smelters, pulp and paper for NOx; iron and steel, petroleum refining for NOx and VOCs) **Transportation** (NOx, VOCs) **Power Generation** (NOx) **Household** (NOx and VOCs) **Agriculture** (off-road vehicles; NOx & VOCs) **Landfill** (VOCs) **Transboundary** (O_3, NOx, VOCs)	medium	high
SMOG: PM_{10} and $PM_{2.5}$	**particulate** (not larger than 10 microns), **acid aerosols** (SO_2 and NO_x)	**Industry** (mining and rock quarries, wood industry, pulp and paper, iron and steel plants, chemical plants) **Transportation** **Power Generation** **Household** (fireplaces) **Agriculture** (minor) **Incineration** (minor) **Transboundary**	low	high

ISSUE	POLLUTANTS	SOURCE SECTOR	DIRECT HEALTH EFFECTS	
			ECOLOGICAL	HUMAN
Acid rain	**SO_2, NO_x, acid aerosols**	**Industry** (smelters for SO_2, NOx and particulate) **Transportation** (NOx and particulates) **Power Generation** (SO_2 and NOx) **Incineration** (minor NOx and SO_2) **Household** (NOx) **Transboundary**	high	low (when excluding acid aerosols: see smog) **or** high
Climate change	CO_2, CH_4, N_2O, CFCs and substitutes, **(O_3)**	see below for CFCs and substitutes **Industry** (pulp and paper, iron and steel for CO_2) **Transportation** (CO_2, N_2O) **Power Generation** (CO_2 and N_2O) **Agriculture** (CH_4) **Landfill** (CH_4) **Household** (CO_2) **Global**	high	high

ISSUE	POLLUTANTS	SOURCE SECTOR	DIRECT HEALTH EFFECTS	
			ECOLOGICAL	HUMAN
Depletion of ozone layer	CFCs, HCFCs and substitutes, halons	**Industry** (air conditioning and refrigerant manufacturers, fire extinguisher producers) **Transportation** (leaking AC units) **Household** (leaking AC and refrigeration units) **Agriculture** (chlorinated & brominated compounds, refrigerants) **Global**	medium	high
Quality of life (noise, odour, taste, discoloration, soiling)	**VOCs, particulates**	**Industry** (construction, dredging, quarries, food processing for particulates; restaurants, pulp and paper, petroleum for odours) **Transportation** (road and bridge construction, vehicle traffic for particulates) **Power Generation** (power transmission lines for visibility) **Agriculture** (ploughing of fields for particulates, spreading of manure for odours) **Sewage Treatment Plants (STP)** (odours) **Householder** (residential construction for particulates)	low	low

ISSUE	POLLUTANTS	SOURCE SECTOR	DIRECT HEALTH EFFECTS	
			ECOLOGICAL	HUMAN
Airborne toxics	organic compounds (many **VOCs**), (**O_3**)	**Industry** (pulp and paper, chemical manufacturers and smelters for dioxins/furans, chlorinated organics; iron and steel for PAHs, heavy metals; mining for heavy metals (e.g., Hg and As) and cyanide) **Transportation** (e.g., benzene, PAHs) **Power Generation** (heavy metals) **Agriculture** (pesticides and herbicides for pest control) **STP, incineration, landfill** (chlorine ammonia, heavy metals) **Household** (solvents and cleansers, paints, pool products, fertilizers for VOCs, PCBs, chlorine and pesticides) **Transboundary** **Global**	high	high

SECTION C

HEALTH EFFECTS: INHALABLE PARTICULATES AND OZONE

Contents

This Section C provides primarily a description of the evidence for the serious health outcomes as measured by hospital admissions and mortality associated with inhalable particulates (IP) and ozone.

In order to ensure that information for these two important pollutants, inhalable particulates (PM_{10}) and ground-level ozone, is presented in a fully integrated fashion with presently on-going Federal-Provincial initiatives, the health effects summary in this Section relied partially on draft documents (in preparation) and references therein, which support these initiatives.

In addition it briefly describes a process of estimating various health effect reductions (ie. public health gains) resulting from reduced emissions of IP and precursors of IP and Ozone. This process is based on a recent study (Hagler-Bailly, 'Health Benefits of Cleaner Vehicles and Fuels' prepared for the CCME, October 1995). Section F provides estimates of reductions in environmental levels of IP and ozone, resulting from reduced emissions associated with various reduction scenarios. The monetized value of the reduced health effects is discussed in Section H.

SECTION C

HEALTH EFFECTS of INHALABLE PARTICULATES and GROUND-LEVEL OZONE

Inhalable particulates and ozone are the two constituents of smog which are of greatest health concern. Very significant evidence is accumulating that current levels of these pollutants are affecting our health.

1. INHALABLE PARTICULATES - PARTICULATE MATTER less than or equal to 10 microns - PM_{10}

1.1 Introduction

Inhalable particulates (IP) are very small solids or liquids that vary in size and chemical composition. IP are less than or equal to 10 micrometers (microns) in diameter and are also referred to as PM_{10} for short. IP can be made up of many constituents such as sulphates, nitrates, elemental carbon, organic compounds, metals and soil dust. IP are easily inhaled. The smaller size particles (those less than 2.5 microns - $PM_{2.5}$), referred to as respirable particulates (RP) can travel to the deepest part of the respiratory tract.

The mechanisms by which inhaled particles damage the lung, and potentially other tissues, are not well understood. Vedal (1995) describes the state of knowledge in this area as follows. Particle effects can be thought of as those resulting from irritation of the lung, an immediate process, and those resulting from damage to lung tissues due to inflammation, a process requiring a longer time period (Widdicombe, 1993). Irritant effects are understood to occur through the cholinergic nerves in the airways and may explain why persons with asthma are more readily sensitive to polluted environments. Particles from different sources and of different chemical compositions exhibit great differences in their ability to induce inflammation under experimental conditions. Recent work has provided evidence that the concentration of surface-complexed iron (Fe^{3+}) on a particle is associated with the likelihood of generating free oxygen radicals and subsequent lung inflammation (Guilianelli, 1993; Keeling, 1994; Tepper, 1994). Although such recent work provides many valuable insights, work on the mechanisms of particle-induced toxicity is in its infancy (Vedal, 1995).

Numerous epidemiological studies, many published in the last five years, have linked exposure to IP levels with serious health effects like cardiac and respiratory hospital admissions and, respiratory, cardiac and total mortality.

1.2 Epidemiology Studies - Mortality

The most troubling observation in the study of health effects of inhalable particles is that exposure to modest concentrations of inhalable particles is associated with an increased risk of death. This observation has been made in several epidemiological studies. The majority of these studies have specifically examined the association between short-term increases in inhalable particle concentrations and *acute* (ie. time-limited) increases in mortality (see Table C-1). Therefore, the design of these studies typically takes the form of comparing variation in inhalable particle concentrations over time in a large urban area to day-to-day variation in mortality statistics. Dockery and Pope (1994) have recently summarized data from eight such studies in the United States in an attempt to estimate the average impact of short-term increases of inhalable particulate concentrations on mortality. The estimate was based on the eight studies, which allowed an estimate of effect size and its variability, and allowed the quantification to be expressed in terms of inhalable particle concentrations (PM_{10}). With respect to general mortality, it was estimated that mortality increased by 1.0% for each 10 $\mu g/m^3$ increase in PM_{10} on the days following the measurement. This estimate ranged from 0.7% to 1.6% for each 10 $\mu g/m^3$ PM_{10} increase in the eight studies that were reviewed. It is important to note that these estimates of daily mortality effects related to increases in PM_{10} were observed at PM_{10} concentrations just above 20 $\mu g/m^3$ (Dockery, 1992; Pope, 1992b; Schwartz, 1993c).

Four of the studies included estimated effects for respiratory and cardiovascular-specific deaths. In each study, cardiovascular-specific mortality was always the largest contributor to total mortality. The estimated summary effect on cardiovascular mortality was a 1.4% increase for each 10 $\mu g/m^3$ increase in PM_{10}. For respiratory-specific mortality, the summary estimate of effect was a 3.4% increase for each 10 $\mu g/m^3$ increase in PM_{10}. Therefore, the effect is strongest for respiratory mortality, the condition for which one would expect to see the strongest effect if the differences were real. A recent study from Greece (Katsouyanni, 1990) also found that the strongest association with mortality was for the subset of deaths due to respiratory causes. The consistency of these estimates across communities suggests that these results are not due to confounding with an unknown or uncontrolled factor and that the **mass concentration of the particle mixture** common to many urban areas, rather than specific chemical species within the mixture, may be responsible for the observed association (Dockery, 1994). Since the summary review of Dockery and Pope in 1994, several cities around the world have been added to the list of cities where mortality increases have been associated at comparable percentage levels with increases for each 10 ug/m^3 rise in PM_{10} levels (Bates, 1996).

Besides knowing whether short-term increases in inhalable particle concentrations are associated with acute increases in mortality, it is also valuable to know whether chronic exposure to higher concentrations of inhalable particles is associated with a higher mortality rate, and not merely whether such exposure hastens death by a few days (Vedal, 1995). The only two studies that have rigorously assessed this issue were based on the US Six Cities Study (Dockery, 1993) and on data collected by the American Cancer Society (Pope, 1995). Although it is relatively trivial to compare and grade cities based on estimates of long-term inhalable particle concentrations and mortality rates, the difficulty with such an attempt is that, since there is no information on

individuals, city-to-city comparisons can be confounded by differences between cities in the distribution of other important risk factors for mortality. This is an example of the so-called "ecologic fallacy" (Morgenstern, 1982). For example, since cigarette smoking is a strong predictor of (ie. strongly associated with) premature mortality, if particle concentrations across cities were associated with rates of cigarette smoking, apparent associations of particle concentrations with mortality might in fact be due to the association between cigarette smoking and mortality. These two studies collected data on smoking status and adjusted the analysis for this strong confounding factor. Both studies found a monotonic, linear association between annual average particle concentration and the risk of death. For each 10 $\mu g/m^3$ increase in PM_{10} as annual averages, there was an 8.4% increase in mortality in the Six Cities Study and a 1.9% increase in the American Cancer Society Study (Vedal, 1995). Since the latter was a much larger study, the estimate of 1.9% derived is more likely to reflect the true relationship.

1.3 Epidemiology Studies - Hospital Admissions

Given the associations observed between changes in ambient inhalable particulate concentrations and mortality, one would expect that hospitalizations, a less adverse outcome than mortality, would also be associated with ambient inhalable particulate concentrations. Most of the epidemiologic studies on particles and hospitalizations examined populations resident either in eastern Canada or in the eastern U.S. Increases in ambient particle concentrations in these regions typically occur together as a complex pollutant mix that includes ozone and acid aerosol, the latter a component of ambient particulate matter. The studies carried out in southern Ontario did not use measures of ambient particle mass, instead using sulphate concentrations as a surrogate for particle concentrations. Using the PM_{10}: sulphate approximate conversion factor (i.e., $PM_{10} \approx SO_4 \times 4$) hospitalizations for all respiratory conditions were estimated to increase 0.8% for each 10 $\mu g/m^3$ increase in PM_{10} (Burnett, 1994). The study conducted in southern Ontario was based on hospital admissions to 168 acute care hospitals over the period 1983 to 1988. Similar studies from Buffalo, N.Y., in which only sulphate concentrations were available as surrogate measures for PM_{10}, found effect estimates ranging from a 1.0% to 2.2% increase in total respiratory admissions for each 10 $\mu g/m^3$ increase in PM_{10}, and approximately a 2.0% increase in asthma admissions for each 10 $\mu g/m^3$ increase in PM_{10} (Thurston, 1994). Recently published data on Toronto specifically, in which $PM_{2.5}$ data were available, showed associations for both general respiratory hospitalizations and asthma hospitalizations with estimated effects of 3.4% and 2.1% for each 10 $\mu g/m^3$ increase in PM_{10}, respectively (Thurston, 1994). Table C-2 (based on Vedal, 1995) summarizes the estimated effects of the recent relevant studies. As for mortality, there is evidence that increases in hospitalizations were observed at PM_{10} concentrations just above 20 $\mu g/m^3$ (Schwartz, 1994b). A threshold analysis was conducted in the study of hospital admissions to Canadian hospitals and particulate matter concentrations. The preliminary results show statistically significant effects on days with PM_{10} equivalent concentrations as low as 25 ug/m^3 (Hagler Bailly, 1995).

Based on a comprehensive analysis of several studies (Dockery and Pope, 1994), respiratory hospital admissions were estimated to increase by approximately 0.8% for each 10 ug/m^3 increase in PM_{10}.

1.4 Epidemiology Studies - Lung Cancer Mortality

Until recently no study was available which adequately assessed inhalable particulate exposure and cancer risk. The US Six Cities Study addressed cancer risk as well as mortality risk. (Dockery, 1993). For each 10 $\mu g/m^3$ increase in PM_{10} as an annual average, there was a 10.5% estimated increase in lung cancer mortality. A much larger study again was that based on American Cancer Society data (Pope, 1995). As for the US Six Cities Study, data were available on risk factors for cancer mortality at the level of the individual. The estimate from this study was 4.0% increase in lung cancer mortality for a 10 $\mu g/m^3$ increase in PM_{10}.

Note: Table C-1 and C-2 use the following guidelines(based on Dockery, 1994) for estimating PM_{10} exposures in epidemiological studies where other measures of particle concentration were reported:

$PM_{10} \approx TSP * 0.55$; $PM_{10} \approx CoH/0.55$; $PM_{10} \approx SO_4 * 4$

Table C-1: **Recent epidemiological studies of the association between short-term increases in PM_{10} and daily mortality in North America (ordered by mean PM_{10} concentration.)**

(Table based on Vedal, 1995)

Location and time	Particle measure	PM_{10} mean (range)	% change in mortality for each 10 $\mu g/m^3$ increase in PM_{10} (95% CI)	reference
St. Louis, MO (1985 - 86)	PM_{10}	28 (1-97)	1.5% (0.1, 2.9)	Dockery, 1992
Kingston, TN (1985 - 86)	PM_{10}	30 (4-67)	1.6% (-1.3, 4.6)	Dockery, 1992
Santa Clara, CA (1980 - 82, 84 - 86)	CoH	35 (N/A)	0.8% (0.2, 1.5) total 3.5% (1.5, 5.6) respiratory 0.8% (0.1, 1.6) cardiac	Fairley, 1990
Philadelphia, PA (1973 - 80)	TSP	40 (26-70)*	1.2% (0.7, 1.7) total 3.3% (0.1, 6.6) respiratory 1.7% (1.0, 2.4) cardiac	Schwartz, 1992b
Utah Valley, UT (1985 - 89)	PM_{10}	47 (1-365)	1.5% (0.9, 2.1) total 3.7% (0.7, 6.7) respiratory 1.8% (0.4, 3.3) cardiac	Pope, 1992
Birmingham, AL (1985 - 88)	PM_{10}	48 (21-80)*	1.0% (0.2, 1.9) total 1.5% (-5.8, 9.4) respiratory 1.6% (-0.5, 3.7) cardiac	Schwartz, 1993c
Detroit, MI (1973 - 82)	TSP	48 (32-73)*	1.0% (0.5, 1.6)	Schwartz, 1991
Steubenville, OH (1978 - 84)	TSP	61 (22-125)*	0.7% (0.4, 1.0)	Schwartz, 1992a

* = 10^{th} and 90^{th} percentiles

CoH - coefficient of haze; TSP - total suspended particulate matter

Table C-2: **Recent epidemiologic studies of the association between short-term increases in PM_{10} and daily hospitalization rate.**

Location and time	Particle measure	PM_{10} mean (range)	% change in hospitalization for each 10 $\mu g/m^3$ increase in PM_{10} (95% CI)	reference
Southern Ontario (1983 - 88)	SO_4	19 (N/A)	1.1% (0.8, 1.5) total respiratory 0.9% (0.6, 1.2) cardiac	Burnett, 1994
Toronto, Ontario (1986 - 88)	PM_{10}	33 (N/A-96)	2.1% (-0.8, 5.1) asthma 3.4% (0.4, 6.4) total respiratory	Thurston, 1994
Minneapolis, MN	PM_{10}	36 (18-58)*	4.5% (1.8, 7.5) COPD 1.6% (0.2, 2.9) pneumonia	Schwartz, 1994c
Birmingham, AL	PM_{10}	45 (19 - 77)*	2.4% (0.8, 4.1) COPD 1.8% (0.7, 2.8) pneumonia	Schwartz, 1994b
New York City and Buffalo, NY (1988 - 89)	SO_4	N/A	1.9% (0.4, 3.4) asthma 2.1% (-0.6, 5.0) asthma 1.0% (0.2, 1.8) total respiratory 2.2% (0.6, 3.8) total respiratory	Thurston, 1992

* 10^{th} and 90^{th} percentiles

(Table based on Vedal, 1995)

2. OZONE

2.1 Introduction

Ozone is a powerful oxidizing agent. While the exact mechanism of toxicity is not known, *in vitro* experiments have demonstrated that ozone interacts with a wide variety of cellular components (e.g., lipids, thiols, proteins) (EPA 1986). The wide range of physiological effects of ozone exposure *in vivo*, may result not only from such direct reactions, but also from the effects of the secondary biochemical reaction products such as ozonides and peroxides formed through reactions with polyunsaturated lipids or free radicals formed directly or indirectly through lipid peroxidation.

Dosimetry studies predict that the terminal bronchiolar and centriacinar regions of the respiratory tract are the target tissue sites for ozone deposition, and hence the most likely targets for tissue damage from ozone exposure. The effect of exercise would be to increase the dose at these sites, and again to increase the likelihood of tissue damage.

The information on exposure to ozone and human response, is provided by **controlled human exposure studies** and **epidemiological studies**. These are discussed briefly in the following sections.

2.2 Controlled Human Exposure Studies

Controlled human ozone exposure studies (i.e., chamber studies) have provided strong and quantifiable exposure-response data on the health effects of ozone. Overall, the responses observed in humans exposed to ozone can be separated into four different categories:

1) Symptoms: Cough, pain on deep inspiration, shortness of breath, throat irritation, and wheezing;

2) Spirometric changes: Decrements in Forced Expiratory Volume in 1 second (FEV_1), decreased forced vital capacity (FVC), total lung capacity, etc.;

3) Airway resistance (i.e., resulting from contraction of the lung fibres): Increases in central or peripheric airway resistance;

4) Airway responsiveness (i.e., predisposition of the airways to bronchoconstriction which can be induced by a variety of stimuli like allergens): To methacholine, allergens, sulphur dioxide, cold air, etc.;

Based on the inherent subjectivity of the measurement of **symptoms** and the variability of assessment methods both within and between, it does not appear feasible to correlate **symptoms** with exposure to ozone. Furthermore, it appears that there is no correlation between **spirometric changes** and **airway resistance** or **responsiveness**. Attenuation of **airway resistance** by atropine with no effects on **spirometry** coupled with the attenuation of **spirometry** response by indomethacin or ibuprofen with no effect on **airway resistance** or **responsiveness** support this categorization and the notion of independent mechanisms.

The evaluation of the toxicity of ozone is hindered by the inability to correlate the effects observed on **spirometric parameters** with actual health effects (ie. at which point does a decrement in FEV_1 affect health status?).

The most sensitive endpoint that is consistently measured appears to be the **spirometric** change, decrement in FEV_1 following exposure to ozone. Dose-response curves were derived for many of the studies and different models were proposed (e.g., exponential, quadratic and log regression model). Basically, the models that include variables for concentration and duration of exposure show a better fit to measured values. In particular, the log regression model proposed by Larsen et. al. (1991), appears to predict quite well the FEV_1 decrements for a concentration range of 80 to 120 ppb and durations of exposure from 1 to 6 hours.

A number of observations can be useful for assesing the health effects of ozone. The exposure levels observed in the hospitalization rates measured in asthmatics correlate very well with the FEV_1 decrements observed in the chamber studies. These decrements in FEV_1 appear to be the most sensitive parameter measured in the human chamber studies and a dose-response curve can be applied to FEV_1 decrements. Asthmatics respond in the same way as normal patients in the chamber studies, except that their inherent condition reduces the baseline values for most of the spirometric parameters. This places them in a more sensitive situation since a decrease in FEV_1 may carry the value below the threshold that triggers asthma attacks.

From this, the most sensitive population appears to be asthmatic patients, or others with compromised lung function. The reduction in FEV_1 appears to be the most sensitive endpoint with effects noticed at doses as low as 80 ppb in the chamber studies. Hospitalization rates (in next section on epidemiology studies) correlate well with the same data showing increased rates with exposure in the same dose range and **below**.

From the data currently available, the most sensitive endpoint appears to be the FEV_1 and the lowest LOEL (ie. lowest observed effect level) observed for this effect in all the chamber studies is 80 ppb (for 1 hr).

2.3 Epidemiology Studies - Hospital Admissions

A number of epidemiological studies have recently been conducted in which **increases in hospitalizations** have consistently been shown to be related to **short term increases in ambient ozone levels**. These effects have been noted at ambient concentrations at or below current standards (80-120ppb), and also below levels associated with **clinical** effects observed in chamber studies (80 ppb).

Hospital admissions provide an objective measure of population adverse effects. This outcome is particularly useful in Canada where access to medical care is universal and cost is not a deterrent to hospitalization. Hospitalizations should, a priori, be a quite insensitive endpoint, since only a very few of the many people who feel poorly, visit the doctor, or become ill enough to stay home from work or school, will be ill enough to require hospitalization. On the other hand, this pattern gives added weight to the results from well-conducted studies in which adverse effects on hospitalizations have been observed, since they represent only the serious outcomes, and are the tip of the iceberg with respect to the number of people adversely affected by the pollutant. Despite this intrinsic insensitivity, hospitalizations as an endpoint have proven to be surprisingly sensitive indicators of adverse health outcomes, due to the extremely large size of some of the populations studied, the accuracy of the data base, and to the advanced statistical methods employed.

2.3.1 Hospital Admissions - Major Canadian Studies

Two recently completed large scale Canadian studies investigated the effect of short-term high ozone concentrations on respiratory morbidity, utilizing hospital admissions as an objective measure.

In the first study (Burnett et. al., 1994), which covered all of Southern Ontario and included data from a population base of 8.7 million people over a period of 6 years, a statistically highly significant association was found between one-hour peak ozone concentrations recorded the previous day and emergency room visits/hospital admissions for asthma, chronic obstructive lung disease (bronchitis, emphysema, bronchioectatis, chronic airway obstruction) and infections (acute bronchitis, bronchiolitis, pneumonia). Other associations were also explored. The relationship was also significant, but somewhat weaker, for 1 hour ozone concentrations recorded the same day, or lagged by two or three days, but was not significant for concentrations recorded four days previously. This relationship was manifested in spring, summer and fall, when ozone concentrations peaked, but was not true for winter, when ozone concentrations were generally low, with the average of 1 hour peak concentrations less than 40 ppb for all months except the four months May-August, in which the overall average was 52 ppb (range 32-70 ppb for 22 districts). Ozone peaks were calculated to account for 5 percent of all respiratory hospital admissions during the months of May to August. Effects were seen in all age groups, but were most marked in infants, and least marked in the elderly, with 15% and 4%

respectively, of overall admissions due to peak ozone levels. These associations between ozone and hospital admissions were consistent across the study region.

Burnett et. al. (1995) have recently completed a more extensive study covering 16 cities in all populated regions across Canada, representing 12.6 million people, or about half the population of Canada in the years of the survey. All cities with a population of over 100,000 for which monitoring data were available were included; from the Pacific coast to the Atlantic they were: Victoria and Vancouver (B.C.), Edmonton and Calgary (Alta), Regina and Saskatoon (Sask), Winnipeg (Man), Windsor, London, Hamilton, Toronto,, and Ottawa (Ont), Montreal and Quebec City (Que), St. John (N.B.), and Halifax (N.S.). Taking into account the variables SO_2, CO, soiling index (Coefficient of Haze or COH), and dew point temperature, a combined relative risk (RR = Incidence rate of disease in the *exposed* group/Incidence rate of disease in the *nonexposed* group) of 1.033 for hospitalizations in spring, summer and fall was attributable to a 30 ppb increase (the approximate difference between the mean and the 95th percentile) in the daily high 1-hour concentration of ozone, recorded 1 day previous to admission. As observed previously there was no increase in relative risk in winter (RR = 0.993), and the increase was highest in summer (RR = 1.043). This increase in relative risk was seen for all cities. The effects of several sampling times were also considered, but the *daily 1-hour maximum concentration* of ozone was statistically the most significant factor explaining the excess hospitalization rate compared to daily averages, average 8am-8pm (daytime) concentration, or maximum 8-h running average. Also as previously, the 1 day lagged concentration was more predictive than the concentration on the day of admission (day 0) or that of two days previously.

It is significant that these associations were observed, in view of the relatively low concentrations of ozone recorded, in comparison to the current Canadian ambient air quality objective of 82 ppb, or to the current U.S. standard of 120 ppb for 1-h values. In the Ontario study, 95 percent of the ozone readings were 92 ppb or less (range for the 22 district was 62 to 118 ppb for the 95th percentile). In the national study, ozone readings were even lower; for the 16 cities in all four seasons, the overall mean of the maximum hourly ozone was 31 ppb and the 95th percentile value was 60 ppb. For the spring-summer period when ozone levels are usually highest and significant correlations with hospitalizations are observed, the national ozone mean and 95th percentile values were 39 and 70 ppb.

From both the Southern Ontario and the Canadian national study (Burnett et al. 1994, 1995), the data do not provide any evidence of a threshold for the effects of ozone. The dose-response appeared to be linear at all concentrations, although statistical significance was not obtained until levels were above 40-45 ppb.

2.3.2 Hospital Admissions - Other North American Studies

The results of the Ontario and the Canadian studies are internally consistent and consistent with other studies. New York City, Buffalo, Detroit, Minneapolis are some of the North American cities where studies were conducted (Thurston et.al., 1992, 1994; Schwartz et.al., 1994b, 1994d,

1994e;). When relative risks are standardized from all 11 studies to a relative risk for a 100 ppb increase in the 1-h maximum ozone value, the eleven estimates of relative risk of respiratory hospital admissions ranged from 1.09 to 1.36 (1% - 36% increased risk). These estimates encompassed S. Ontario, 16 cities across Canada, and 7 U.S. cities, including one on the west coast. The lower end of the range, as observed in the two Burnett et al. studies (1994, 1995) was about 1.1, a value which most likely represents the average, since the studies include an extremely large and diverse population from different geographic areas.

In summary, these studies provide strong evidence that environmental exposure to ozone at levels commonly encountered in Canada and U.S.A., perhaps in concert with other pollutants, is associated with adverse respiratory effects that are sufficiently severe to require hospitalization. This association has now been consistently observed in a number of studies conducted in cities geographically spread across North America, differing in pollutant levels, size, population characteristics , etc. and differing also in the statistical methods employed.

In spite of such coherent evidence on the hospital admissions associated with ozone, there was a recent proposal (Vostal, 1995) advocating that the existing US EPA ozone standard of 120 ppb is overly protective due in part to excessive conservatism at the time of promulgation when adequate scientific data were lacking. In this proposal, the definition of "effect" was very restrictive, relying entirely on the results of clinical exposure studies and completely ignoring the currently available epidemiological studies.

2.4 Epidemiology Studies - Mortality

Recent epidemiological evidence suggests that there may be an acute mortality effect associated with day-to-day fluctuations in ozone levels that occur in cities in North America. The evidence as a whole, however, is somewhat inconsistent because there are some studies that find a statistically significant association with ozone and some studies that do not. In five of the nine studies, which showed a positive association, the associations were weak.

Therefore, it can be stated that an association ozone with mortality is weak and awaits refinement/clarification in other studies. There exists the possibility that ozone-related mortality effects may be detectable only when other pollutants are present (occur) simultaneously. Particulate matter is a good candidate, but other pollutants, particularly irritant acid species, may also be involved.

3. ESTIMATION of PUBLIC HEALTH GAINS (i.e., HEALTH EFFECT REDUCTIONS for both IP and Ozone)

3.1 Other Health Effects

In addition to the serious health outcomes (i.e., hospital admissions, mortality) discussed in the previous sections, other measures of health effects associated with ozone include, hospital emergency room visits for asthma ('Asthma ERV's), asthma symptom days, minor restricted activity days, and acute respiratory symptom days. For IP, other measures of health effects include adult chronic bronchitis, hospital emergency room visits, asthma symptom days, restricted activity days, acute respiratory symptom days and bronchitis in children.

3.2 Estimation Process

A recent study (Hagler-Bailly, 'Health Benefits of Cleaner Vehicles and Fuels' prepared for the CCME, October 1995) developed and applied a process for estimating reductions in health effects (i.e., public health gains) as a result of reductions in environmental levels of ozone and IP. The health effect reduction estimates developed in this section were patterned on the process developed in the Hagler-Bailly study. One of the inputs required for this process is the estimated change (i.e., reductions or in some cases increases) in environmental concentrations of IP and ozone, resulting from changes in emissions associated with the various reduction scenarios. These are discussed in Section F.

Briefly, the process of estimating reductions in health effects, as developed by Hagler-Bailly consisted of the following. For each health effect (e.g., mortality, respiratory hospital admission), available epidemiological studies were discussed and those appropriate for quantitative use were selected. From these studies a range of concentration - response coefficients was derived (i.e., a 'high', 'central' and a 'low' value) for each health effect category. In order to provide average estimates and for simplicity, the health effect reduction estimates shown later in this section used the 'central' value of the concentration-response coefficients.

The two examples from Hagler-Bailly (1995) which follow, briefly illustrate the development of the concentration-response coefficient from the selected epidemiological study and its use in the calculations of reduced health effects.

Cardiac hospital admissions (CHAs) for PM_{10} were based on the Southern Ontario results reported by Burnett et. al. (1995) for sulfates. Burnett et. al. (1995) reported a 3.3 percent

increase in CHAs for a 13 ug/m^3 increase in sulfate when ozone was included in the model. The sulfate based results were converted to PM_{10} assuming a ratio of sulfate to PM_{10} of 0.18 in Ontario (Dann, 1994). Thus, 3.3 percent of the average daily CHAs per million population (i.e., 14.4) in the study area gives the number of additional daily CHAs per 13 ug/m^3 sulfate. Dividing by 13 gives the daily CHAs per one ug/m^3 sulfate [0.033 x (14.4 x 10^{-6}) ÷ 13 = 3.66 x 10^{-8}]. Multiplying by 0.18 gives the daily CHAs per one PM_{10} ug/m^3. The 'central' estimate of CHAs for PM_{10} is thus as follows:

$$\textbf{Central Daily CHA for } PM_{10} = 6.6 \times 10^{-9} \times \triangle PM_{10} \times POP_j \qquad (1)$$

CHA - Cardiac Hospital Admissions
$\triangle PM_{10}$ - Change in Daily (24-hour) PM_{10} in an area j
POP_j - Population in area j

Respiratory hospital admissions (RHAs) for ozone were based on the Burnett et. al. (1994) results when sulfates were included in the model. Burnett et al. (1994) report a 4.5 percent increase in RHAs for a 50 ppb increase in the daily high-hour ozone concentration. This was applied to the average daily RHAs during the study period, which was in this case the months of May through August only. The average daily RHA during that period from 1983 to 1988 was reported as 13.3 per million population. Thus, multiplying 13.3 by 0.045 and dividing by 50 gives an estimate of the daily RHA per million population per ppb daily high-hour ozone. This provides the 'central' estimate as follows:

$$\textbf{Central Daily RHA for Ozone} = 1.2 \times 10^{-8} \times \triangle O_3 \times POP_j \qquad (2)$$

RHA - Respiratory Hospital Admissions
$\triangle O_3$ - Change in Daily high-hour O_3 in an area j
POP_j - Population in area j

3.2 Results

The estimated public health gains (ie., reductions in health effects) for IP and ozone associated with the scenarios below are summarized in Tables C-3 to C-6. Further notes and assumptions are given in the footnotes to these tables.

The following scenarios (i.e., 2 program scenarios and a base case scenario) were addressed:

1) Existing + Readily Available Reductions (with growth)

2) 45 % Reduction of 1990 NOx and VOC emissions

3) Base Case - Unreduced Emissions (growth only) from 1990

Both Tables C-3 and C-4 show the estimated reductions or increases in health effects associated with ozone and inhalable particulates, respectively, for the above three scenarios ***relative to 1990***. In both Tables C-3 and C-4, the first column describes the scenarios. In Table C-4, the scenarios are partitioned by a solid shaded row. The second column indicates the expected increases or reductions in ozone levels in Table C-3 and in secondary particulate levels (i.e. nitrates and secondary organic aerosols - SOA) in Table C-4, when compared to 1990. Negative values in the second column indicate an increase in ozone or secondary particulate levels, leading to an expected deterioration in air quality. These scenarios in turn lead to an increase in the projected health effects (***relative to 1990***) as indicated by the negative values.

Briefly, the base case scenario (i.e., # 3 - 'unreduced emissions, growth only, from 1990') would be expected to lead to a greater deterioration in air quality than scenario # 1 (i.e., 'existing and readily available reductions') in which some of this deterioration is offset by reductions in NOx and VOC emissions. Scenario # 1 reflects the smaller number of health effect increases relative to 1990. Finally, achieving one of the main goals of the smog plan, scenario # 2 (i.e., '45 % reduction of 1990 NOx and VOC emissions'), shows substantial public health gains relative to 1990.

It is more informative to use such a health benefit analysis in a comparative rather than in an absolute sense. For this reason, the focus of these estimates is a comparison of the two positive program scenarios, scenarios # 1 and 2, to the base case scenario (i.e., # 3 - 'unreduced emissions, growth only, from 1990'. Tables C-5 and C-6 illustrate this comparison for ozone and inhalable particulates respectively. The public health gains summarized in Tables C-5 and C-6 include mortality, cardiac and respiratory hospital admissions, as well as additional morbidity effects. It can be seen that there are a significant number of annual health effect reductions expected for the health outcomes of hospital admissions and mortality. It should be recognized that these serious health outcomes are just the tip of the iceberg as can be seen from the numbers associated with the other morbidity effects. These indicate that a large number of people can be adversely affected by these pollutants.

The public health gains in Tables C-5 and C-6 have been further summarized in terms of mortality and selected morbidity effects in Table 2 of the discussion paper entitled "Towards a Smog Plan in Ontario".

During the period up to 2015, additional health effect reductions are expected from reduced levels of suphates (i.e. secondary IP) as a result of reduced emissions of sulfur dioxide in the US states south-west of Ontario, because of the US Clean Air Act reduction measures pertaining to SO_2. Also a reduction in IP levels are expected from the CCME Clean Vehicles and Fuels Initiative (Hagler Bailly, 1995), in particular from meeting the sulphur content of 200 ppm in fuels.

The monetized value of these reduced health effects is discussed in Appendix H.

14/5/96

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Table C - 3. Estimated Reductions or Increases in Health Effects for Ozone (relative to 1990)

(Reductions or Increases per Year, for the year 2015, when Reductions/Increases Fully Achieved)

(Units for Health Effects: Number of Cases or Events per year)

SCENARIOS (Leading to Reductions or Increases in Ozone Levels)	*PPB Ozone Reduction* ppb	Mortality	Respiratory Hospital Admissions	Asthma ERVs	Asthma Symptom Days	Minor Restricted Activity Days	Acute Respiratory Symptoms
Existing and Readily Available	-15	0	-2	-6	-1304	-5589	-13329
Reductions (with growth). (6)	-40	-1	-5	-17	-3478	-14904	-35544
	(Increases)	(Increases)	(Increases)	Increases	(Increases)	(Increases)	(Increases)
45 % Reduction of 1990	125	2	15	53	10869	46576	111076
NOx and VOC Emissions	250	5	30	106	21738	93151	222152
Base Case-Unreduced Emissions	-110	-2	-13	-47	-9565	-40987	-97747
(growth only) from 1990. (6)	-240	-5	-28	-102	-20868	-89425	-213266
	(Increases)	(Increases)	(Increases)	Increases	(Increases)	(Increases)	(Increases)

Notes and Assumptions:

1) PPB Ozone Reduction = Annual Sum of Daily Peak Hour Ozone concentrations minus 40 ppb (Based on emission reductions and and modelling - See Section F

2) Respiratory Hospital Admissions-Dose/Response Based on Southern Ontario study (Burnett et al./1994)

3) Dose/Response for All Other Endpoints (ie. mortality, asthma ERVs, asthma symptoms days, etc.) based on the 'central' estimates of the Hagler-Bailly study

4) Health effects are estimated for the Ontario section of the Windsor-Quebec Corridor (WQC) - Population assumed: 9,840,625 (per Hagler-Bailly study).

5) Asthmatic Population - For the estimate of Asthma Symptom Days the asthmatic population was assumed to be 4.7 % of the total population.

6) Note that negative values denote INCREASES in ozone concentrations (ie. air quality is worse) and hence the change in health effects is actually an INCREASE not a reduction.

Table C - 4. Estimated Reductions or Increases in Health Effects for Inhalable Particulates - PM10 (relative to 1990)

(Reductions or Increases per Year, for the year 2015, when Reductions/Increases Fully Achieved)

{Units for Health Effects: Number of Cases or Events per Year}

SCENARIOS (Leading to Reductions or Increases in PM10 Levels)	Region of Ontario	Avg. Daily PM10 Conc. Reduction ug/m3	Mortality	Adult Chronic Bronchitis	Respiratory Hospital Admissions	Cardiac Hospital Admissions	ERVs	Asthma Symptom Days	RADs	Acute Respiratory Symptoms	Bronchitis in Children
NITRATE (ie. PM10) Reductions	WQC(Ont)	-0.06	-4	-26	-2	-1	-138	-1621	-23915	-73958	-255
From: NOx Reductions-Ontario		(Increase)									
Existing+ Readily Available	Rest of Ont.	-0.04	0	-2	0	0	-12	-140	-2013	-6470	-24
Reductions (with growth) - as for		(Increase)									
Ozone (7), (9).											
SECONDARY ORGANIC AEROSOL	WQC(Ont)	-0.1	-6	-44	-3	-2	-231	-2701	-39858	-123264	-425
(SOA) Reductions		(Increase)									
From: VOC Reductions-Ontario	Rest of Ont.	-0.03	0	-2	0	0	-9	-105	-1509	-4853	-18
Existing+Readily Avail. Reductions		(Increase)									
(with growth) - as for Ozone(7) (9)											
NITRATE (ie. PM10) Reductions	WQC(Ont)	*0.4*	*26*	*175*	*11*	*9*	*923*	*10804*	*159431*	*493056*	*1700*
From: NOx Reductions-Ontario		*0.9*	*58*	*394*	*25*	*21*	*2076*	*24309*	*358720*	*1109376*	*3824*
45 % Reduction of 1990 NOx &	Rest of Ont.	*0.3*	*3*	*17*	*1*	*1*	*90*	*1053*	*15094*	*48528*	*178*
VOC emissions - as for Ozone (7)		*0.6*	*5*	*33*	*2*	*2*	*180*	*2107*	*30189*	*97055*	*356*
SECONDARY ORGANIC AEROSOL	WQC(Ont)	*0.3*	*19*	*131*	*8*	*7*	*692*	*8103*	*119573*	*369792*	*1275*
(SOA) Reductions		*0.6*	*39*	*263*	*17*	*14*	*1384*	*16206*	*239147*	*739584*	*2549*
From: VOC Reductions-Ontario	Rest of Ont.	*0.1*	*1*	*6*	*0*	*0*	*30*	*351*	*5031*	*16176*	*59*
45 % Reduction of 1990 NOx &		*0.2*	*2*	*11*	*1*	*1*	*60*	*702*	*10063*	*32352*	*119*
VOC emissions - as for Ozone(7)											
NITRATE (ie. PM10) 'Reductions'	WQC(Ont)	-0.6	-39	-263	-17	-14	-1384	-16206	-239147	-739584	-2549
From: NOx Reductions-Ontario		(Increase)									
Base Case - Unreduced Emissions	Rest of Ont.	-0.4	-3	-22	-1	-1	-120	-1405	-20126	-64704	-237
(growth only) from 1990 - as for		(Increase)									
Ozone (7) (9)											
SECONDARY ORGANIC AEROSOL	WQC(Ont)	-0.4	-26	-175	-11	-9	-923	-10804	-159431	-493056	-1700
(SOA) 'Reductions'		(Increase)									
From: VOC Reductions-Ontario	Rest of Ont.	-0.15	-1	-8	-1	0	-45	-527	-7547	-24264	-89
Base Case - Unreduced Emissions		(Increase)									
(growth only) from 1990 - as for											
Ozone (7) (9)											

NOTE: The PM 10 Concentration Reductions Nitrates and SOAs (ie. PM10 concentrations in italics in shaded cells are RANGES for the WQC(Ont) and Rest of Ont.

NOTE: All estimates(ie. numbers in italics) corresponding to these reduction ranges are also RANGE of HEALTH EFFECT ESTMATES

ERV - Emergency Room Visits;
RAD - Restricted Activity Days
Notes and Assumptions:
1) Average DAILY PM10 Concentration Reduction : This is based on an annual reduction averaged over every day of the year .
(Based on emission reductions and modelling - See Section F)
2) Respiratory and Cardiac Hospital Admissions-Dose/Response Based on Southern Ontario study (Burnett et al./1995)
3) Dose/Response for All Other Endpoints (ie. mortality, ERVs, asthma symptoms days, etc.) based on the 'central' estimates
of the Hagler-Bailly study
4) Health effects are estimated for the Ontario section of the Windsor-Quebec Corridor (WQC) - Population assumed: 9,840,625 (per
Hagler-Bailly study) and the Rest of Ontario - Population: 1,279,375.
5) Asthmatic Population - For the estimate of Asthma Symptom Days, the asthmatic population was assumed to be 4.7 % of the total
population.
6) For Adult Chronic Bronchitis, assumed that the change in annual average PM10 concentration is the same as the daily change in PM10 (ie. column C).
Also assumed an adult population of 7,184,948 for the WCQ (from Hagler Bailly); for the Rest of Ont. 908,357 (ie. 1,279,375 - [1,279,375] x 0.29 = 908,357);
where 29 % is the average <20 population from all the WCQ counties of the Hagler Bailly study;
7) For both of these scenarios, it was assumed that US NOx and VOC emission reductions are the same as Ontario's.
8) For Bronchitis in Children, assumed that the change in annual average PM10 concentration is the same as the daily change in PM10 (ie. column C).
Also assumed a child population of 2,655,677 for the WCQ (from Hagler Bailly); for the Rest of Ont. 371,018 (ie. 1,279,375(total) - 908,357(adult) = 371,018;
9) Note that negative values denote INCREASES in PM-10 concentrations and INCREASES in health effects

Table C-5. Estimated Annual Reductions in Health Effects for Ozone in the Year 2015 for the Two Program Scenarios, Relative to the Base Case 'Unreduced Emissions, growth only, from 1990' Scenario. (for the Ontario part of the Windsor-Quebec corridor)

{Units: Number of cases or events per year}

Scenarios	Mortality	Respiratory Hospital Admissions	Asthma ERVs	Asthma Symptom Days (000s)	Minor Restricted Activity Days (000s)	Acute Respiratory Symptoms (000s)
Existing+Readily Available Reductions *relative to* BASE CASE - Unreduced emissions (growth only) from 1990	2-4	11-23	41-85	8-17	35-75	84-178
45 % Reduction of 1990 NOx and VOC emissions *relative to* BASE CASE - Unreduced emissions (growth only) from 1990	4-10	28-58	100-208	20-43	86-183	209-435

Table C-6. Estimated Annual Reductions in Health Effects for Inhalable Particulates in the Year 2015 for the Two Program Scenarios, Relative to the Base Case 'Unreduced Emissions, growth only, from 1990' Scenario. (for all of Ontario)

{Units: Number of cases or events per year}

Scenarios	Mortality	Adult Chronic Bronchitis	Respiratory Hospital Admissions	Cardiac Hospital Admissions	ERVs (000s)	Asthma Symptom Days (000s)	RADs (000s)	Acute Respiratory Symptoms (000s)	Bronchitis in Children (000s)
Existing+Readily Available Reductions *relative to* BASE CASE - Unreduced emissions (growth only) from 1990	59	394	25	21	2	24	359	1113	4
45 % Reduction of 1990 NOx and VOC emissions *relative to* BASE CASE - Unreduced emissions (growth only) from 1990	118-173	797-1169	50-75	41-62	4-6	49-72	725-1064	2249-3300	8-11

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SECTION D

IMPACT OF EXPOSURE ON VEGETATION IN ONTARIO

SECTION D

IMPACT OF OZONE EXPOSURE ON VEGETATION IN ONTARIO

1. Introduction

Ozone is the most damaging of all atmospheric pollutants affecting crops, forests, ornamentals and natural vegetation. Its effect on plants was first recognized in the late 1950's. Early research focussed on short term exposures and the resulting visible symptoms of leaf damage. These studies formed the basis for the development of air standards to protect sensitive crops against these types of effects. However, as research methodologies improved, and it was possible to assess plant response under more natural, field conditions, it became apparent that ozone can cause growth and productivity losses with or without evidence of visible symptoms. These types of impacts result from season long exposure to varying levels of ozone intermixed with periods of low or intermediate levels, which can allow plants to recover from previous exposures. It is generally accepted now that cumulative (sum of hourly values) exposure to ozone levels in excess of 40-60 parts per billion (ppb) over a three month growing season is a better indicator of the damaging effects of season long ozone levels on crop and forest growth than exceedances of a single hourly value. However, until this more biologically meaningful measure or index of plant response is fully developed, the levels of ozone in excess of Ontario's existing 1-hour ambient air quality criterion of 80 ppb can be utilized, as it too, is linked with vegetation impacts.

In 1989, it was determined that the value of crop and ornamental production in Ontario could be increased by up to $70 million annually by achieving the existing 1-hour air quality criterion of 80 ppb. The impact of ozone on vegetation in Ontario and other countries is now being re-evaluated as part of standards setting reviews in Canada, the U.S.A. and Europe. Although these studies are not yet complete, the exposure:response scenarios that are emerging do confirm the damaging effects of ozone on vegetation in Ontario based on the magnitude and extent of seasonal ozone levels that are experienced.

While scientific efforts continue in the search for a biologically meaningful measure of plant response to season-long ozone exposure, visible evidence of damage to sensitive crops in Ontario continues to be documented by Ministry staff each year. In some cases, foliar symptoms also affect the marketability of edible produce.

This document will summarize the efforts which were undertaken by MOEE staff in 1989 to assess and quantify the adverse impact of ozone exposure on terrestrial vegetation (crops, ornamentals and forests) in Ontario. It will also summarize ozone standards setting activities that have been under way in Canada since 1989 as part of the multistakeholder NOx/VOC science initiative.

2. Oxidant Effects on Vegetation

Photochemical oxidant air pollution was first recognized in 1944 when toxic effects on vegetation were observed in Los Angeles [1]. Later, grape 'stipple' near San Bernardino, California was ascribed to atmospheric ozone [2]. Tobacco 'weather fleck' observed at Beltsville, Maryland in 1952, and in southern Ontario in 1955 also was attributed to ozone [3,4]. Cause-effect studies to determine the relationship between atmospheric ozone and unexplained needle injuries on Eastern white pine trees were started in Canada in 1959 [5] and in the U.S. in 1961 [6].

From a dose:response perspective, comprehensive reviews of the available literature were made by Jacobson [7] and Linzon et al. [8] in the mid-1970's, and concentration:time profiles for acute foliar injury were developed for sensitive, intermediate and less sensitive species. Based on these and other findings, Guderian et al. [9] developed a set of maximum acceptable ozone concentrations which, if met, would provide protection of vegetation from short term, acute exposures. For a 1 hour exposure, the threshold for foliar injury to sensitive, intermediate and less sensitive plants was determined to be 75, 180 and 250 ppb, respectively.

The importance of short term controlled environment ozone exposures and associated thresholds for foliar response has been overshadowed in recent years by the shift in research priorities to outdoor, season long ozone exposures. The main reason for this shift was evidence indicating that foliar injuries resulting from short term exposures under greenhouse or controlled environment conditions were not an acceptable surrogate for ozone impacts on crop yield or tree growth over longer periods.

The most comprehensive regional program which has emerged to address the issue of full season ozone impacts on agricultural crop yield is the National Crop Loss Assessment Network (NCLAN) in the U.S. The results of this program are described in numerous publications [10-13]. In the most recent NCLAN assessment of yield losses, a three parameter Weibull model [14] was used to predict production losses of major crops in the U.S. from seasonal ozone mean concentrations of 40, 50 and 60 ppb. The results of these model predicted losses, which were based on NCLAN style field exposures for 11 crops, averaged 4.0, 7.6, and 10.1% for seasonal means of 40, 50 and 60 ppb, respectively [12]. The seasonal mean referred to in the NCLAN studies was determined by averaging the hourly ozone levels for either a 7 or 12 hour period of the day (0900-1600 or 0800-2000 hours) for three consecutive months of the summer growing season (usually, June-August).

Utilizing the data sets from the various NCLAN experiments and other similar field studies, many retrospective attempts have been made to find a better exposure:response function or index that would accurately characterize crop yield response to ambient ozone exposure [19-30]. This has been a difficult task, as the ubiquity of ozone makes it difficult to set up low exposure control treatments to assess the impact on crop or forest growth without significant modification of variables that could, in and of themselves, contribute to yield. It is beyond

the scope of this document to thoroughly review this issue; however, at the time of the Ministry's 1989 assessment, a number of major findings had emerged that were considered in the selection of an ozone exposure:response index to characterize productivity impacts in Ontario.

It was apparent from several of the general reviews of this area that no one exposure:response index could accurately describe the response of all crop species to the many variations in ozone exposure over an entire growing season. However, the rigorous statistical search for relationships between crop response and a large number and variety of ozone averaging periods or exposure indices generally pointed to the importance of peak concentrations and cumulative exposure indices that summed the hours of exposure above mid-range levels of ozone over various periods of the day when plants would be susceptible to ozone uptake. However, in many cases, these relationships were mathematically complex and difficult to interpret from a standard setting basis [31].

It was also recognized that exposure indices based on peak and cumulative concentrations have their own limitations in that neither directly address the length of episodic events, intervals between episodes, the sensitivity of the target organism at the time of exposure or the amount of pollutant that enters the plant or canopy [29]. Lee et al. [20] examined a number of exposure weighting systems in the analysis of some of the NCLAN data. They found that while no single index was best in relating ozone exposure to crop response, the indices that performed the best were those that cumulate (sum) the hourly concentrations over time, emphasize (weight) concentrations over 60 ppb and phenologically weight the exposure over the plant growth stage. In another evaluation of possible exposure indices, Musselman et al. [19] evaluated a total of 163 ozone indices using the NCLAN data set. Again, no one index was best for all crops, suggesting that conclusions from many of the retrospective single or double crop exposure:response evaluations that had been performed by other investigators should be considered within these limitations.

The scientists involved in the NCLAN program also examined some of their data to investigate the use of alternative exposure:response indices [25]. Using three differential weightings of the hourly ozone concentrations (peak vs. non-peak, time of day of the exposure, and total hourly solar radiation) the authors concluded that the NCLAN seasonal mean dose statistic was a reasonable exposure:response index, and that, contrary to the findings of Lefohn, Lee and others, the most effective exposure:response index is not well described by the weighting of the data for peak concentrations.

In more recent years, the search for a biologically relevant exposure:response function has continued, and during this time, mid-range concentrations have emerged as additional factors to consider in the development of a crop response function. This will be discussed in greater detail in Section 4.

3. 1989 Assessment Methods and Results

A full description of the methods utilized in 1989 ozone impact assessment can be found in Pearson [33] . This section will briefly summarize the findings of that assessment.

3.1 Exposure:Response

At the time of the 1989 Ontario study, there was no scientific agreement as to the best exposure index to represent plant response to ozone exposure. However, there appeared to be growing evidence which indicated that the desirable index must adequately characterize all of the important exposure dynamic factors (concentration, duration, episode frequency, threshold) [21] and that seasonal mean indices employed in the NCLAN assessment and economic impact analysis may not be among the best. It was also recognized that the search for a better response index had been based on mathematical exercises using the NCLAN data set, and that this effort in itself may also may be flawed, as the conditions under which the NCLAN experiments were run may not have adequately represented the important biological factors that are known to affect plant response. For example, the role of temperature increases inside the chambers had not been considered and may negate some of the findings regarding the importance of peak ozone concentrations. This is because high ozone levels often occur at times of the day when temperatures also are high, and plant stomates are closed to maintain water balance. This scenario would result in much reduced sensitivity of the plant, as ozone would not be able to enter the stomates to the same extent as under conditions more favourable for gas exchange.

In the absence of a clear universally acceptable and fully biologically relevant exposure index with which to assess the impact of ozone exposures on Ontario vegetation, a decision was made in 1989 to proceed with an analysis of the existing North American crop response database from a seasonal mean perspective and to relate these findings to ozone exposures (seasonal means) in Ontario. While it was recognized that the seasonal mean exposure index may not be the best predictor for vegetation impact, and therefore, not universally appropriate as an air quality standard, one of the main reasons cited for its limitations was a lack of any consistent relationship with peak hourly values [21] which are generally recognized as being important in vegetation response evaluations.

In deciding to utilize the seasonal mean statistic in the 1989 vegetation impact analysis it was, therefore, important to determine if peak hourly ozone occurrences in Ontario were related to seasonal means calculated from these data sets. Statistical correlations and regression were run on the rural only (117 site-years) and combined (rural+urban) data set (389 site-years) for the period from 1974-1988. The results of this analysis confirmed that unlike the more vast and geographically diverse U.S. network, peak annual one hour maxima were correlated with seasonal means, both in rural and combined rural/urban locations in Ontario. Based on this relationship, it was concluded that seasonal means at or below 40 ppb (the lowest level used in the predictions of U.S. crop loss projections based on the NCLAN work) would be achieved in rural areas of Ontario by the attainment of the existing one hour

annual maximum ozone concentration of 80 ppb. From earlier acute exposure:foliar response data, it was also concluded that attaining the 80 ppb hourly level also would provide some degree of short-term foliar injury protection to most of the sensitive species [9]. It would not, however, provide complete short or long-term protection to a few very sensitive species or during periods when climatic conditions and crop phenology are most conducive to maximum plant sensitivity.

In summation, although it was recognized that the seasonal mean ozone exposure index may not be the best predictor for vegetation impact due to its inability to differentiate infinitely large numbers of ozone exposure profiles which could have very different impacts on vegetation, it was utilized in the 1989 assessment for several reasons:

1) there was no generally accepted alternative index which could be applied without extensive biological research/evaluation under Ontario exposure conditions

2) an analysis of the Ontario ozone database revealed that, unlike the situation in the U.S., the relationship between peak hourly values and the 7-hour seasonal mean for rural sites was reasonably well correlated; while this did not greatly improve the predictive power of the seasonal mean in terms of plant response, it did indicate that under these exposure profile conditions, there was a tendency for a more consistent pattern of peak exposure relative to average seasonal means.

3) for several of the crops evaluated, the impact of various seasonal mean ozone exposures was based on crop research under Ontario conditions; therefore, some of the problems of utilizing exposure:response data which were generated in the NCLAN study under hourly ozone profiles which may not have been characteristic of those producing similar seasonal means in Ontario, have, for some crops, been partially overcome.

The other factor that was taken into consideration was that although the seasonal mean index may not have a high degree of predictive power, there appeared to be enough 'weight of evidence' to indicate that if met, it would be protective under most situations. The fact that all indices under examination were correlated with each other, supports this conclusion, in that achieving reductions to meet one index level would also result in reductions in other index values. Similarly, it was apparent that reductions in ozone to meet a one hour maximum value (80 ppb) also would translate into reductions in a seasonal mean index.

3.2 Ozone Monitoring in Ontario

In Ontario, the first indication of transboundary ozone movement across Lake Erie was documented in 1960 following extensive work on the relationship between the incidence of weather fleck on tobacco and meteorological conditions associated with the build-up of ozone [15]. Since 1960, a number of large-scale meteorological investigations [16-18] have confirmed these early findings and shown that high ozone levels generally are associated with

regional southerly/southwesterly air flows associated with back or centre of the high pressure situations. These investigations have indicated a significant ozone contribution from the U.S. during the summer months with an even greater contribution during episode periods. Contributing to these influx patterns are relatively minor, localized downwind urban effects which can add to the already elevated background levels.

A network of oxidant monitors was established in Ontario in the early 1970's. In 1974, the first ozone specific, chemiluminescent based monitors were introduced. During the following 15 years, the network was continually upgraded, with the addition of stations in many rural and urban areas. In 1988, there were valid data for 47 monitoring stations, with about one third of those in rural areas or small rural towns.

The Ontario ozone air quality database (1974-1988) was analyzed using the 7-hour seasonal mean statistic (June-August / 09:00-16:00 E.S.T.). A summary of ozone concentrations at five selected rural and urban locations, representative of most areas of the province was prepared from this analysis. In all cases except for Dorset, the monitoring stations selected for summary analysis had at least 10 years of continuous data. Results for Dorset were included in this table because of intensive forest research underway at that site in recent years.

Using these data (9 sites) and results from an additional 20 sites in Ontario where ozone monitoring had been performed for a minimum of 8 years (29 sites total), the average (1974-1988) 7-hour seasonal means were computer contoured using the kriging technique. The ozone database was also examined to establish contours of maximum and minimum seasonal means (based on average of 2 overall highest years plus a third high year at each monitoring station).

3.3 Vegetation Impact

3.3.1. Agricultural Crops.

In an effort to estimate the severity of crop yield loss in those portions of Ontario subjected to potentially injurious summer ozone concentrations, a thorough review was undertaken for all major crop species grown in Ontario. The literature review consisted of published research reports, unpublished documents and internal reports from government agencies and universities dealing with productivity losses under field conditions in North America. The results of this review for the 12 most frequently assessed ozone sensitive crops are presented in the complete assessment document [33].

In all cases, the review of the literature focused on experimental findings in which crops were exposed to 7 or 12 hour per day seasonal mean ozone concentrations in a range typical of those encountered in Ontario. These included seasonal means of 40 and 50 ppb. Crop loss data for exposures greater than these two values were included only if the publication

included yield models (Weibull, Quadratic or Linear) which were subsequently solved to generate average yield loss for these two seasonal mean ozone concentrations.

The literature review also was limited to research in which crop productivity was assessed under field conditions utilizing open-top field chambers, air exclusion systems, air plenum systems, closed-top field chambers or chemical protectants. In many of these experiments the impact of additional factors, such as soil water stress, disease control or mixtures of ozone with other air pollutants was assessed.

In the previous (1984) Ontario assessment (32), the average yield loss values for each crop were derived based primarily on the experience and professional judgement of the authors. To overcome the weaknesses of this approach, the 1989 assessment was modified to incorporate a mathematical adjustment factor approach based on defined assumptions. The 1989 estimates also utilized variability in seasonal ozone exposure severity to delineate the spatial extent of seasonal ozone impacts. To avoid the limited and selective use of a few specific research results to arrive at regional crop loss values, as was the case with several other U.S. estimates [12,13,34-39], an adjustment factor approach was developed which would permit the use of all available ozone response data for each crop. As described, the adjustment of the average yield values for seasonal means of 40 and 50 ppb (actual reported yield loss values or model derived calculations) was predicated on assumptions in three areas - geographic variability, agronomic variability and experimental variability. In all cases, the adjustment of yield loss estimates arising from the research resulted in lower (more conservative) estimates of potential yield loss under real world conditions.

3.3.2. Forests.

On the basis of controlled ozone exposures, many tree species indigenous to Eastern North America are classified as being susceptible to foliar ozone injury [41-44]. Direct injury to tree foliage by ozone has been demonstrated repeatedly in experimental situations, and in nature as well. Concentrations of ozone, at least in some forested areas, are sufficient to cause injury [44-46]. These ozone effects can alter the productivity, successional patterns, and species composition of forests [47] and enhance activity of insect pests and some diseases [48].

A 1988 review [49] provided a critique of available experimental approaches, summarized tree response data from controlled fumigations and discussed the difficulties in extrapolating experimental findings to regional, economic damage estimates.

In Ontario, foliar symptoms associated with ozone injury to white ash and Eastern white pine had been observed by MOE staff extensively throughout most areas where the crop damage was found. However, it was concluded that until such time as growth impact studies were undertaken, the role of ozone on forest growth could not be quantified. It was noted however, that based on the trend in Ontario of decreasing ozone levels in a north-south gradient, any impact of ozone on commercial forestry, which predominates in the northern

areas of the province, should be much less than in rural areas of southern Ontario. Although economic impacts in southern Ontario could not be reliably quantified at that time, there was a growing body is mounting research evidence that ozone concentrations similar to those experienced in southern Ontario have the potential to affect productivity of a large number of sensitive hardwood and softwood species, many of which have significant commercial value as fine furniture and veneer woods.

3.3.3. Ornamentals.

Experimental progress in the case of woody ornamentals has been more advanced than for herbaceous species. This has resulted from the dual role of many species as both ornamental and forest stock. In their role as ornamentals, the majority of trees and shrubs are planted as single specimens with full exposure to ambient air. This contrasts with the forest situation where a variety of canopy and stand factors must be quantified before valid extrapolations to natural settings can be made. As a result, much of the forestry oriented experimental research that has been conducted on tree seedling response to ozone has particular value in terms of ornamental effects.

In a review of the tree seedling research reported up to 1988, Pye [49] summarized ozone effects on biomass, height and photosynthesis for 43 tree species or hybrids. From this summary, which was based on an evaluation of 25 controlled exposure, experimental studies, and on additional work which had been published since that time [50-54] there was strong evidence that ozone exposures common to most areas of the U.S. and Ontario were causing growth reductions in many sensitive landscape plantings.

Tree species common to Ontario which have demonstrated ozone sensitivity (biomass, height, photosynthesis) under controlled ozone exposure conditions included: maples (sugar, silver, red), ash (white, green), spruce (white), white pine, poplar (hybrid), cottonwood, cherry, walnut, sycamore, white birch and red oak. Although in many of the experimental studies, ozone impacts varied significantly (reductions and stimulations), the response to seasonal exposures in the 40-60 ppb range for over half of the studies was reported as at least nominal growth reductions [49].

On the basis of these findings and the similarity in the range of ozone exposures in Ontario to those of many of the research studies, it was estimated that ornamental nursery supply operations in southern Ontario (Ozone Regions 4 and 5), including Christmas tree production, suffered an annual productivity loss of 5% with a range of 2-7%, depending on exposure and climatic variation. These estimates were well below the experimental detection limit for growth effects on the most sensitive species which was determined [49] to be approximately 9%. Given the relatively limited species testing that had been conducted at that time, and the high likelihood that other species not yet evaluated were experiencing similar adverse growth effects, it was concluded that these loss estimates could conservatively be applied to all ornamental woody species cultivated for sale in Ontario.

There was also evidence that ozone could injure many annual and perennial grass species commonly utilized in turfgrass production in Ontario [55,56]. Although these studies have not examined growth or productivity impacts, it was concluded that the similarity of these species to the forage species already evaluated supported the application of an average growth reduction similar to that for ornamental trees (5% with a range of 2-7%).

3.4 Economic Benefit of Ozone Control

Using the crop loss functions and estimated impact on ornamentals provided in the 1989 assessment (33), Donnan [40] calculated the monetary value of the crop production benefits that would accrue to Ontario farmers and those involved in the supply of ornamental trees, nursery sod and Christmas trees.

In the case of agricultural crops, the annual minimum, mean and maximum benefits were $14.4, $38.8 and $61.4 million, respectively. For ornamentals, the annual minimum, mean and maximum values were $2.2, $5.7 and $8.2 million, respectively.

These estimates of production increases were predicated on information from staff in the Ontario Ministry of Agriculture and Food who concluded that the removal of this type of production stress would not result in increased production input costs. It was also concluded that production increases of this magnitude would not be expected to depress the prices of these crops in Ontario; however, some effect on prices might occur if production increases were experienced over a wider region than Ontario, and if this did occur, the estimates of production increases could slightly overestimate the benefits of improved air quality. If this were the case, it would need to be re-assessed, using more current production figures and prices for these commodities.

3.5 Summary and Conclusions of 1989 Assessment

The 1989 report summarized the results of extensive efforts undertaken in Ontario to assess the impact of ozone on all types of terrestrial vegetation and to provide a scientific basis for the derivation of economic benefits for an ozone control program. Other objectives were to assess the adequacy of Ontario's existing one hour ozone criterion of 80 ppb, in terms of providing protection against adverse impacts on crops, ornamentals and forests in the province.

In the case of agricultural crops, the estimation of production losses was accomplished by a thorough review of the scientific literature as well as many unpublished government and university reports and conference proceedings and the development of a database for crop response to 7-hour seasonal mean ozone concentrations of 40 and 50 ppb. A total of 19 crops was assessed in this manner, and for 12 of the 19, a comprehensive adjustment factor approach was utilized in the estimation of crop loss due to ozone exposure in Ontario to compensate for geographic, agronomic and experimental variability in the research results.

Based on these findings and an analysis of the Ontario ozone database, it was determined that the value of agricultural crop production in Ontario could increase annually by an average of $39 million with a range of $14 to $61 million per year with reductions in ozone to seasonal mean concentrations of less than 40 ppb. Statistical analysis of the ozone data from 1974-1988 revealed that seasonal means of less than 40 ppb could be achieved in Ontario by control efforts designed to meet the existing one hour ambient air criterion of 80 ppb.

In the case of ornamentals, including landscape trees, turfgrass and Christmas trees, productivity losses were estimated at an average of 5% with a range of 2-7% in the southern portion of the province experiencing ozone seasonal means in the 40-60 ppb range. The economic value of these impacts was estimated at $6 million with a range of $2 to $8 million per year, again based on achieving ozone reductions to meet the 1 hour ambient air criterion of 80 ppb.

Although foliar injuries have been documented on many forest species in Ontario, the state of knowledge at that time was insufficient to develop a reliable estimate of productivity losses. However, it was noted in the report that in Ontario, the major portion of the forest industry is located in an area of the province where ozone levels normally are lower than in the agricultural production areas of southern and central Ontario.

4. Efforts Underway Since 1989

Since 1989, efforts have been under way as part of the NOx/VOC Management Plan to re-evaluate the Canadian air quality objectives for ozone, based on vegetation response. The Vegetation Objective Working Group (VOWG) was established with the overall goal/objective being: to review the current state of knowledge on ozone damage to Canadian vegetation and develop a position on the form and level of an ambient ozone objective to protect vegetation.

The VOWG met for the first time in June 1992, and further clarified its terms of reference as follows:

- to review existing Canadian National Ambient Air Quality Objectives for ozone and make recommendations on their suitability (with respect to protecting vegetation)
- to evaluate available data on ozone damage to field crops, horticultural crops and forestry
- to develop the form and level of an ambient ozone objective to protect vegetation
- if necessary, to make recommendations for additional research required to develop the objective

Prior to the establishment of the VOWG in early 1992, another similar work group consisting of vegetation experts from across Canada and the United States had been assembled in October, 1989. This WG, referred to as the VOC/NOx/O3 Impacts Expert Work Group - Vegetation Component, met in October 1989. The purpose of the WG was to undertake an assessment of the 7-hour seasonal mean objective that had been proposed by the Federal/Provincial Advisory Committee on Air Quality and to make recommendations regarding an appropriate objective for the protection of vegetation.

As required by the NOx/VOC consultation process, the recommendations of this WG were presented in December 1989. The following conclusions were reached:

1. The proposed 7-hour based, June-August growing season mean of 32 ppb ozone is inappropriate as a Canadian air quality objective.

2. A different type of biologically-based, long-term measure of exposure for vegetation is required, which reflects more accurately the dynamics of ozone exposure and plant response.

3. For the purpose of the NOx/VOC management plan, the 82 ppb 1-hour objective is reasonable, although it may not protect some sensitive plant species or ecosystems (note that the Canadian objective of 82 ppb differs from the Ontario criterion of 80 ppb only because of mathematical calculations involved in converting the measured concentrations from microgram/cubic meter to parts per billion).

4. The ambient air quality monitoring data bases for ozone, NOx, and VOCs are inadequate for non-urban regions of the country at the sites of agricultural, forest and natural ecosystems at risk.

As a follow-up to these recommendations, an ozone/vegetation effects workshop, sponsored by the Canadian Institute for Research in Atmospheric Chemistry (CIRAC) was held in February 1991. This workshop also served as a forum for discussion of a research proposal which had been developed under contract to the Atmospheric Environment Service (AES), Environment Canada.

Specifically, the workshop focused on three main questions and developed responses as follows:

1. Is the current 1-hour air quality objective for ozone of 82 ppb scientifically defensible?

Based on the information available in the literature (primarily foliar response data), the answer was a "no" at this time.

2. **Does the 1-hour air quality objective for ozone provide protection for known sensitive crop species against acute injury or against effects on yield and productivity?**

A clear answer to this was not possible, because it is known that acute injury may or may not have an effect on yield and productivity.

3. **Can there be a single, scientifically defensible national ambient air quality objective for ozone?**

The answer to this question was "yes", but it would require a more environmentally encompassing approach to derive a new air quality objective for ozone. This is due to the fact that different regions of Canada differ in their climate, ozone exposure characteristics, duration of the plant growth season and in the types of crops grown and their sensitivity to ozone.

The contract to explore these issues consisted of a retrospective analysis of the available international data on crop response to ozone exposure via open-top chambers with and without charcoal filtration, and commenced in July 1992.

The initial findings of the NCLAN assessment revealed that the number of stations with scientifically valid data for this type of dose:response assessment were small relative to the total project. However, there were sufficient data to undertake a modified version of the statistical analysis that was proposed. The results of this assessment indicated that mid-range concentrations of ozone were just as important as peak concentrations in determining exposure:response relationships.

In an effort to further explore this finding, an additional contract was let to undertake an analysis of the European Open Top Chamber Program. The conclusions reached indicated that the frequency of concentrations in excess of about 35 ppb was related to crop loss. The second phase also provided additional material to the VOWG on which to address concerns raised in the scientific literature regarding the importance of short term peak concentrations versus lower, mid-range concentrations.

At its most recent meeting, the VOWG evaluated the findings from the contracted exposure:response assessment and considered a number of directions and possibilities for completing the assigned task of recommending the form and level of a vegetation-based air quality objective. These included an analysis of cumulative exposure indices developed in both Europe and the U.S. These include the AOT40 (Accumulated Exposure over a Threshold Concentration of 40 ppb) and the SUM06 indices (sum of ozone hourly values over 60 ppb). The results of this analysis are not yet complete; however, it has become apparent that the level of individual crop loss detail that was developed in the 1989 assessment will not be possible from the data sets that are available. There is no question,

however, from this work that crops and other vegetation in Ontario continue to be exposed to levels of ozone that are higher than in any other part of Canada and well above critical cumulative ozone exposure index levels that are emerging as candidates for a national ozone objective from current exposure:response analyses.

As a result, it now appears that the earlier (1989) estimates of vegetation-based benefits that would result from achieving Ontario's current ozone objective of 80 ppb for one hour will require re-evaluation once a decision has been made on the new exposure:response function. However, based on the most recent findings of the VOWG, it appears unlikely that the overall economic estimates of benefits from an ozone control program will decrease in magnitude.

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SECTION E

EMISSIONS AND AMBIENT AIR MONITORING OF NO_X, VOCS AND IP IN ONTARIO

APPENDIX E

EMISSIONS AND AMBIENT MONITORING OF NO_x, VOC AND IP IN ONTARIO

1. Nitrogen Oxides, Volatile Organic Compounds and Inhalable Particulate Emissions Affecting Ontario

The majority of Ontario's anthropogenic nitrogen oxides (NO_x), volatile organic compounds (VOC) and particulate emission sources are located in Southern Ontario, spanning from Windsor to Cornwall of the Windsor-Quebec City Corridor. This region has approximately eighty five percent of Ontario's population (~9.5 millions) and has several major urban centers with many industries and commercial establishment. Windsor, Sarnia, London, Kitchener-Waterloo, Hamilton, Ottawa and the Greater Toronto Area are the larger urban areas. Smaller urban centers or industrial communities such as Chatham, Cambridge, Nanticoke, Kingston and Cornwall also contribute to the overall emissions.

The provincial 1990 anthropogenic emissions of NO_x and VOC are estimated to have been 659 and 868 kilotonnes respectively. Table E-1 is an 1985-2015 emissions estimation and projection of the NO_x and VOC emissions for Ontario. The projected growth of emissions is derived from the National Emission Inventory and Projections Task Group (NEIPTG), NEIPTG Consensus National Base Case Forecast, Version 2.1, March 1996 with an update supplied by Environment Canada to MOEE in April 1996.

It should be noted that the methods currently used to obtain emission estimation from sources have varying degree of accuracy or completeness, depending on the quality of available source information and accuracy of the applied emission estimation methodologies. For industrial process and stationary fuel combustion, NO_x, VOCs and particulate emissions are estimated from source information obtained from voluntary surveys using best available methodologies. When compiling emission inventories, emission profiles derived for specific emission sources are always used where available, since they are the most accurate. If they are not available, then material balance emission factors are used where appropriate, since they are considered as less accurate emission profiles. If material balance emission factors are not appropriate, then engineering judgement emission factors are used. Other less accurate emission estimations, based on limited source and release information, are the application of generic emission factors for sources of similar pollutant release activities. As a last resort, expert technical judgement based on emission history and anticipated activities or equipment specifications can be used when no other better means of emission estimation is applicable.

There are considerable uncertainties in the emission estimations of inhalable and respirable particulates (IP and RP). In particular, open sources of fugitive emissions from road dust, construction, surface erosion and agriculture activities may be over- estimated by using the

limited selections of generic emission factors available from U.S. EPA and Environment Canada.

The transportation sector accounts for more than 60% of the total NO_x emissions, while about 20% of the total emissions are from major point source combustion processes including power generation, smelters and primary metal processing (Figure 2 of Towards a Smog Plan for Ontario document). Major anthropogenic sources of VOC include transportation, fuel combustion, petrochemical and refinery processing, surface coating, solvent usage and fugitive emission from fuel marketing. NO_x and VOC emissions have both decreased from 1985 to 1995 due to reduction initiatives and reduced economic activities.

Natural VOC emissions are significant sources of O_3 precursors, especially during the summer months. They are believed to be released in larger quantities from northern Ontario where dense forests and vegetation dominate the landscape. The natural VOC annual emissions for Ontario were estimated to be about 2,400 kilotonnes for 1990. During hot summer days, total quantity of natural VOC emissions released in southern Ontario would be comparable to VOC emissions from human activities. Natural VOC's are very reactive and possess high ozone forming potential.

1990 Ontario emissions of total particulates and IP from industrial sources, non-industrial fuel combustion, transportation and miscellaneous urban sources (excluding open sources), as estimated by MOEE, are about 310 and 210 kilotonnes, respectively. Open sources of fugitive emissions from road dust, construction, surface erosion and agriculture activities account for >90% of the provincial total particulate matter emissions and they account for >70% of the provincial IP emissions (Figure E-1). Open sources of fugitive emissions are extremely difficult to quantify accurately and better estimation methodology or study is needed. Therefore, further study is needed to review and to improve on the emission estimation of these sources. As well, secondary formation of sulphate and nitrate as a result of atmospheric chemistry and long range transport are major sources of local and transboundary RP (i.e. $PM_{2.5}$).

In an urban airshed, transportation activities, residential wood combustion, road dust and construction are common sources of particulate emission. Particulates are also emitted from industrial processes include fuel combustion, mining, metal smelting and many material handling processes. Such industrial sources generally have some form of emission control devices installed in order to comply with ambient air quality criteria. In addition, a number of industries have fugitive sources of particulate emissions which can contribute to the total emissions.

Open fugitive source emissions from road dust, construction and surface erosion depend on economic activity and meteorology (i.e. precipation and wind speed) but are not easy to control. As described in Appendix F, source-receptor model studies indicate that open fugitive sources are not the major contributors to finer portion of IP emissions. The percentage contribution of these open sources to IP emissions are therefore uncertain.

Occurrences of high levels of smog in Ontario are often influenced by high NO_x, VOC and particulate emissions from U.S. regions. Table E-2 provides an emissions profile of the U.S. states south of the Ontario Great Lakes region that likely contribute to the long range transport of O_3, NO_x, VOC and IP/RP into Ontario.

2. Smog Monitoring In Ontario

In Ontario, high concentrations of ground-level ozone (> 80 ppb) are typically recorded on hot sunny summer days. Such days are often associated with slow moving high pressure weather system located south of the Ontario Great Lakes region which brings ozone, NO_x and VOC from the U.S. into southern Ontario. As a result, a large contribution (50% or greater) to the Ontario ozone component of smog are due to the long range transport of ozone and its precursors from the neighbouring U.S. states south of the Great Lakes.

Ambient monitoring results from monitoring stations throughout Ontario, especially in the Windsor-Quebec City Corridor, have shown that there has been a high number of exceedances of Ontario's one-hour O_3 criterion (80 ppb) every year (Figure E-2). The number of exceedances annually varies with meteorology and occurs more frequently in southern Ontario, especially near the shorelines of Lake Huron and Lake Erie, and in areas downwind of or within the Toronto-Hamilton urban centers (Figures E-3 and E-4).

To control O_3 over large regions where natural and man-made VOC concentrations are high, NO_x emission reductions from man-made sources are most effective. In urban centers, reductions of NO_x and VOC are both required to effectively lower the ozone formation in nearby areas.

The monitoring sites for IP in Ontario are located in major urban centers with significant commercial and industrial activities (Figure E-5). A five-year trend study of IP (PM_{10}) from available 24-hr PM_{10} sampling data across Ontario has shown that higher ambient concentrations of IP are generally found in industrial areas (Figures E-6 and E-7) having heavy industries and in densely populated urban centers such as Toronto.

There are limited ambient monitoring data for RP. However, secondary formation of sulphate and nitrate as a result of atmospheric chemistry and long range transport are major sources of local and transboundary RP ($PM_{2.5}$) fine particulate matter. The declining trends of ambient concentrations of NO_x and SO_2 (Figures E-8 and E-9) from 1977 to 1994 can be considered as indirect indicators of RP reductions from Ontario sources. More conclusive ambient monitoring, source and ambient characterization of IP and RP and better emission inventory are needed for the development of inhalable and respirable particulate (IP and RP) criteria.

It should be noted that certain ambient air VOC from urban and industrial sources, besides contributing to the photochemical production of ground-level ozone, are also airborne toxics.

For example, benzene, an airborne toxic VOC has been detected in measurable quantities in various urban and industrial areas of Ontario (Figure E-10). Thus, any environmental initiative on VOC reduction will also reduce airborne toxics.

Table E-1 Baseline Emission Estimates (No New Reduction Activities after 1996)

Sector	Baseline Emission (Kilotonnes/year)						
	1985	1990	1995	2000	2005	2010	2015
NOx Emissions							
TRANSPORTATION SECTOR:							
Cars	135	114	92	81	81	86	91
Light Duty Trucks - Gasoline	34	32	32	30	42	62	66
Light Duty Trucks - Diesel	1	1	1	1	2	1	1
Heavy Duty Trucks - Gasoline	3	3	2	2	4	1	1
Heavy Duty Trucks - Diesel	111	117	91	74	59	55	51
Off-Road Vehicles - Gasoline	9	11	11	12	12	13	14
Off-Road Vehicles - Diesel	92	104	112	131	138	148	159
Other (marine, aircraft)	20	19	18	19	22	23	24
Sub-Total:	**405**	**401**	**359**	**350**	**360**	**389**	**407**
ONTARIO HYDRO	**95**	**77**	**35**	**58**	**58**	**58**	**58**
IND./COMM./RESIDENTIAL SECTOR:							
Copper and Nickel Production	49	53	10	19	26	32	39
Iron and Steel Production	22	22	24	28	31	33	35
Petroleum Refining	14	14	15	18	20	21	22
Pulp and Paper Industry	10	9	10	12	13	15	17
Cement and Concrete Manufacture	9	10	8	10	12	14	16
Other Industrial	34	46	49	57	64	71	79
Residential	16	16	16	17	17	16	15
Commercial and Institutional	9	8	10	11	11	12	13
Miscellaneous	3	3	3	4	4	4	4
Sub-Total:	**166**	**181**	**145**	**176**	**198**	**218**	**240**
Total:	**666**	**659**	**539**	**584**	**616**	**665**	**705**
VOC Emissions							
TRANSPORTATION SECTOR:							
Cars	198	166	116	104	105	111	117
Light Duty Trucks - Gasoline	54	44	39	38	39	42	45
Light Duty Trucks - Diesel	-	-	-	-	-	-	-
Heavy Duty Trucks - Gasoline	5	3	2	1	3	3	3
Heavy Duty Trucks - Diesel	14	13	12	11	11	12	13
Off-Road Vehicles - Gasoline	28	35	39	31	30	34	39
Other	25	26	25	27	29	31	33
Sub-Total:	**324**	**287**	**233**	**212**	**217**	**233**	**250**
IND./COMM./RESIDENTIAL SECTOR:							
Solvent Use	115	124	134	142	149	155	161
Surface Coatings	111	122	137	146	156	167	179
Fuel Wood Combustion	107	115	106	105	105	105	105
Fuel Marketing	34	35	35	37	40	43	46
Petroleum Refining	25	35	36	40	44	49	55
Iron and Steel Production	30	25	31	36	42	46	50
Petrochemicals	10	12	13	16	19	22	25
Pulp and Paper Industry	8	8	8	10	11	12	13
Dry Cleaning	5	6	6	7	7	7	7
Other Industrial	72	76	81	94	108	122	138
Miscellaneous	21	22	24	29	29	29	29
Residential - Fuel Combustion	1	1	1	1	1	1	1
Sub-Total:	**539**	**581**	**612**	**663**	**711**	**758**	**809**
Total:	**863**	**868**	**845**	**875**	**928**	**991**	**1059**

TABLE E-2. GREAT LAKES STATES, PERIMETER STATES AND ONTARIO 1990 NOx, VOC AND PM-10 EMISSIONS.

(thousand metric tonnes)

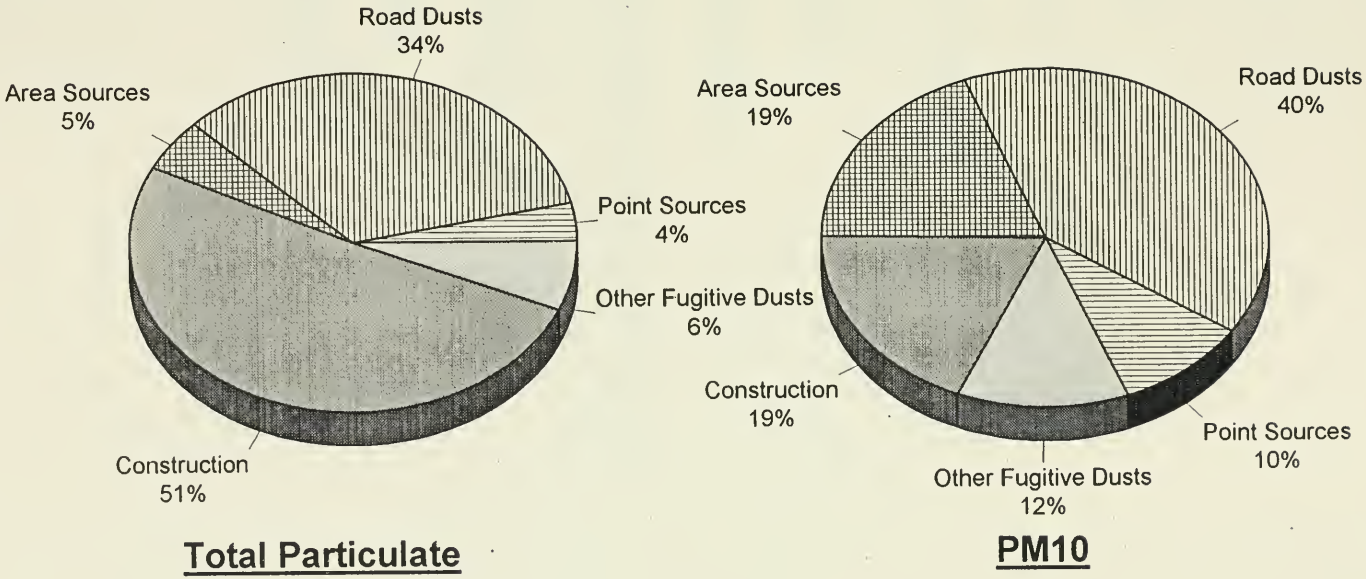
	NOx	VOC	PM-10*
GREAT LAKES STATES			
Minnesota	361	366	1,288
Wisconsin	398	384	802
Illinois	863	829	1,458
Indiana	879	539	855
Michigan	713	685	983
Ohio	1,004	803	1,392
Pennsylvania	855	820	1,138
New York	718	908	1,316
subtotal	5,791	5,334	9,232
PERIMETER STATES			
Iowa	265	210	890
Missouri	536	435	1,558
Kentucky	561	316	511
West Virginia	423	512	214
Virginia	419	533	602
Maryland	295	260	404
Delaware	60	106	64
New Jersey	363	551	461
subtotal	2,922	2,923	4,704
TOTAL OF ABOVE	8,713	8,257	13,936
ONTARIO	659	868	760

* PM-10 emissions include all PM-10 sources such as transportation, area, point, and fugitive dust sources (construction, road dusts, agricultural tilling, wildfires and wind erosion).

Sources:
Ontario: Ontario MOEE, April 1996.
U.S.: USEPA, National Inventory 2-Tier Report Generator Database, May 1995.

Figure E-1

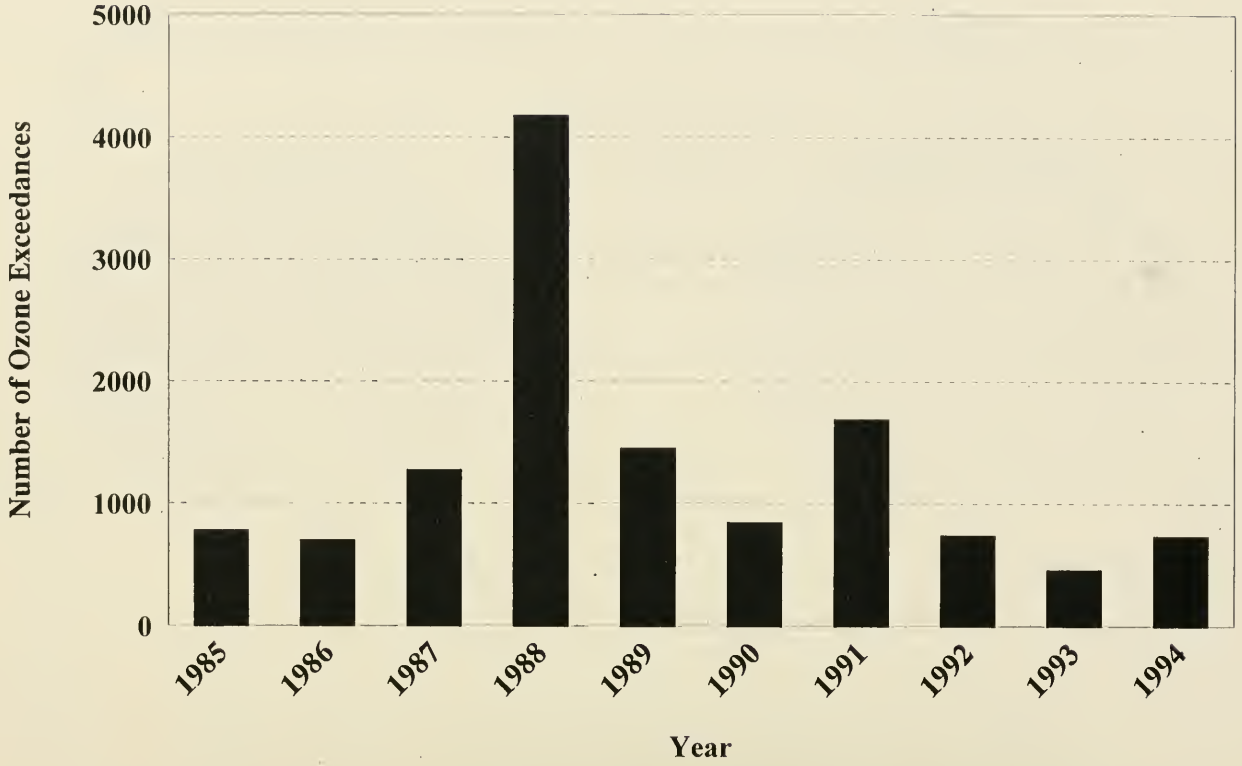
Particulate Emissions in Ontario - 1990



Point Sources - major industrial sources
Area Sources - non-industrial sources plus some minor industrial sources

Figure E-2

10-Year Trend for Ozone Exceedances (1985-1994)



Note: 23 sites operated over 10 years 1-Hour Objective = 80 ppb

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Geographical Distribution of 1-Hour Ozone Exceedances Across Ontario (1994)

Figure E-4

Average Number of Days (1988-1993) with Ozone Concentration in Excess of Objective (80 ppb for a one-hour period)

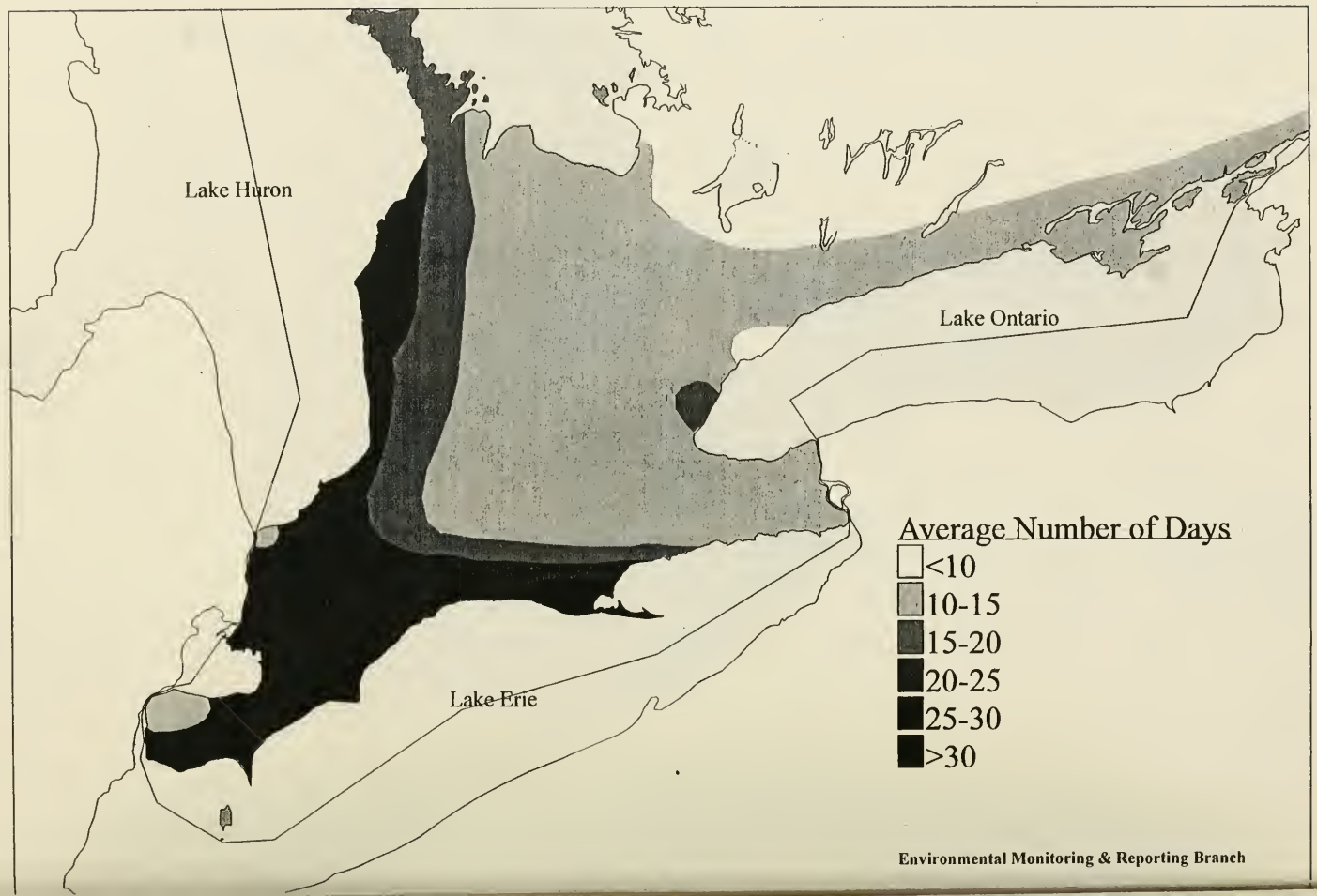

Figure E-5

Geographical Distribution of Annual Mean PM10 Concentrations Across Ontario (1994)

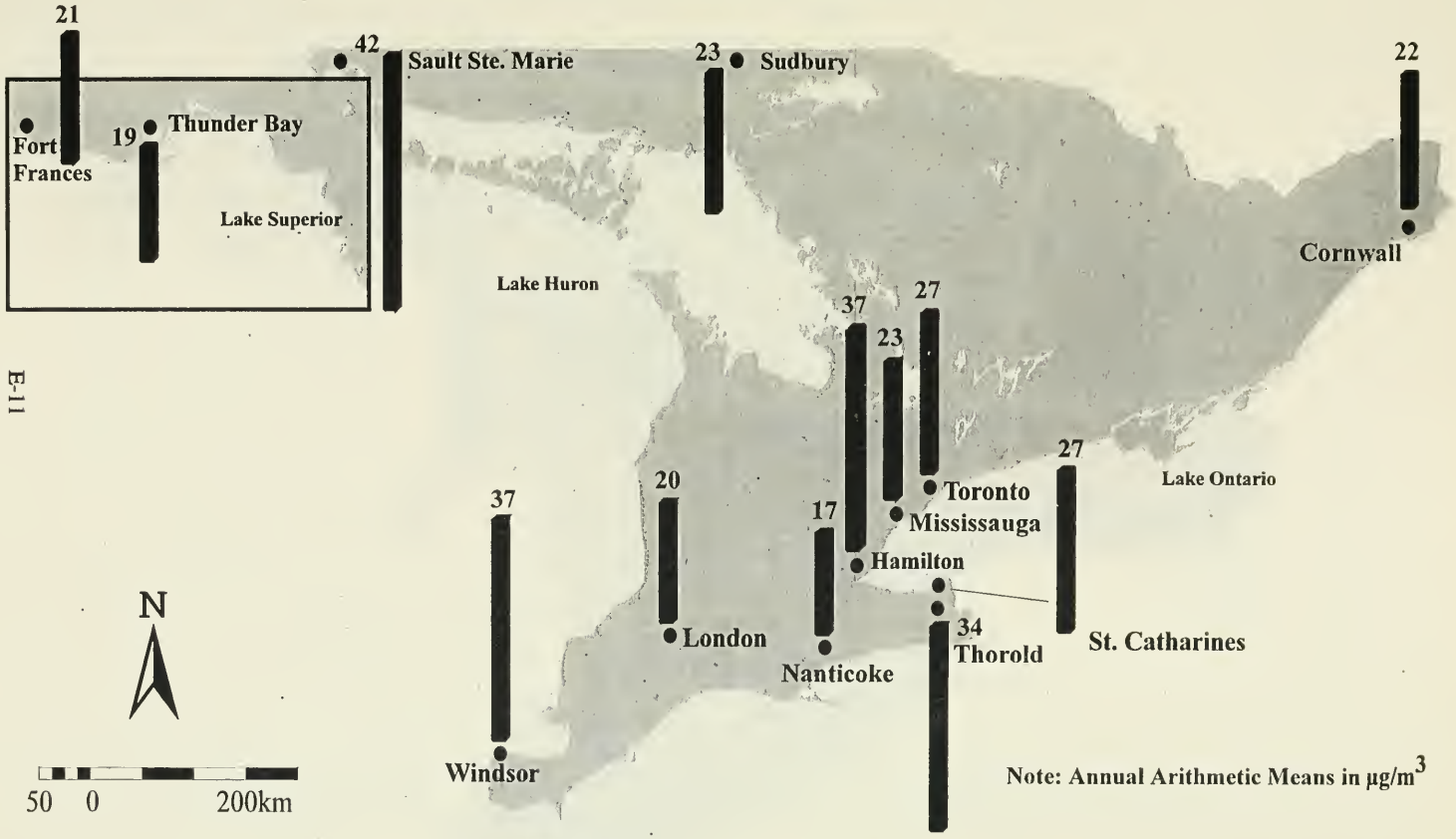

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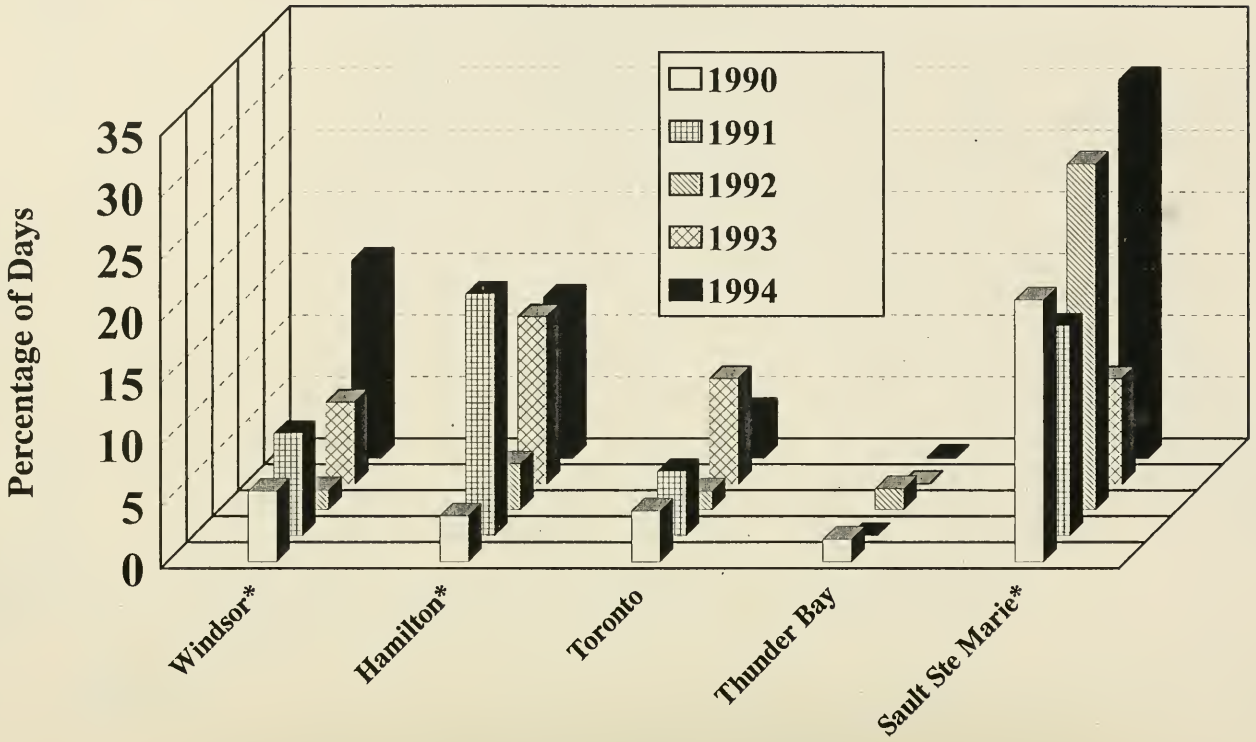
Figure E-6

Percentage of Days PM_{10} > 50 $\mu g/m^3$ Across Ontario (1990 - 1994)



* Site impacted by source

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Figure E-7

Boxplots of PM10 Concentrations at all Sites (1990-1994)

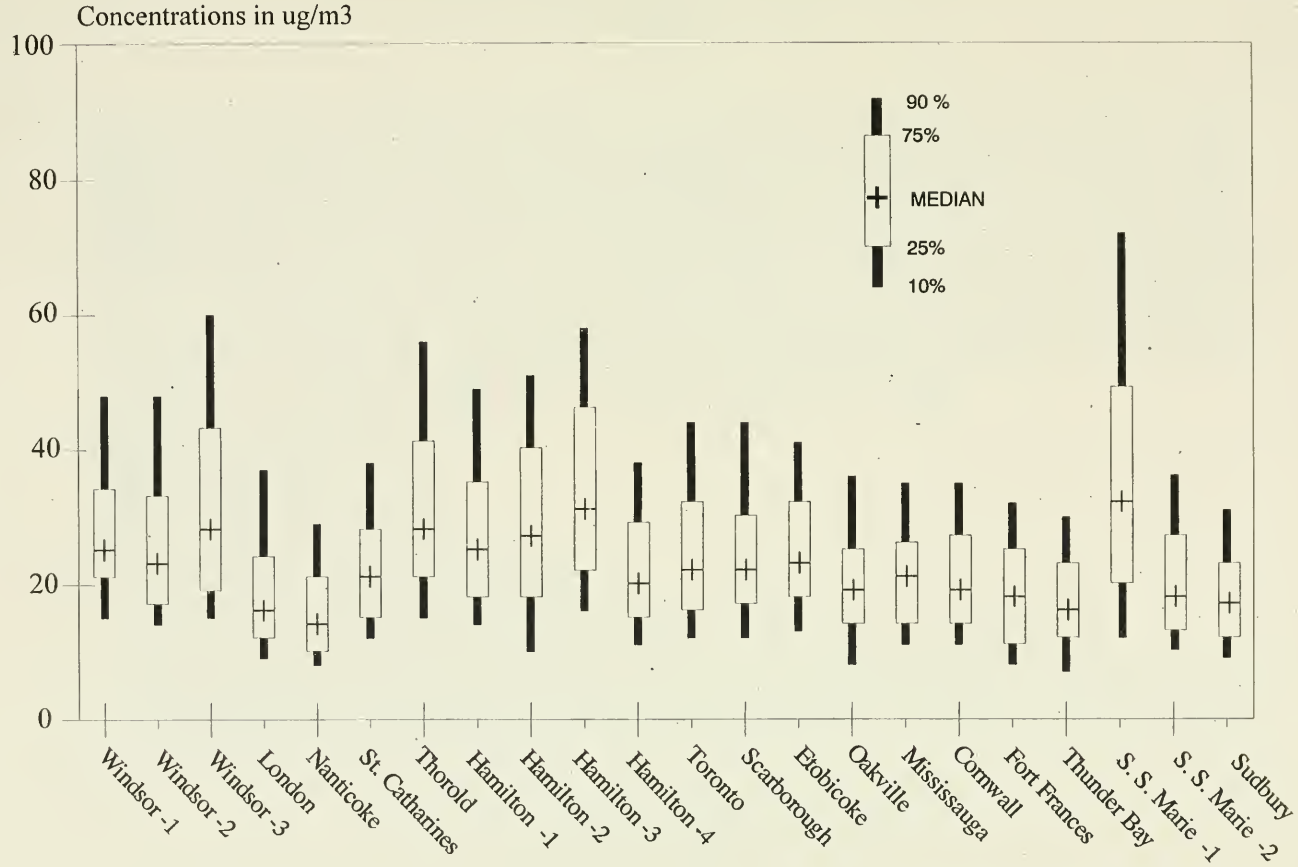

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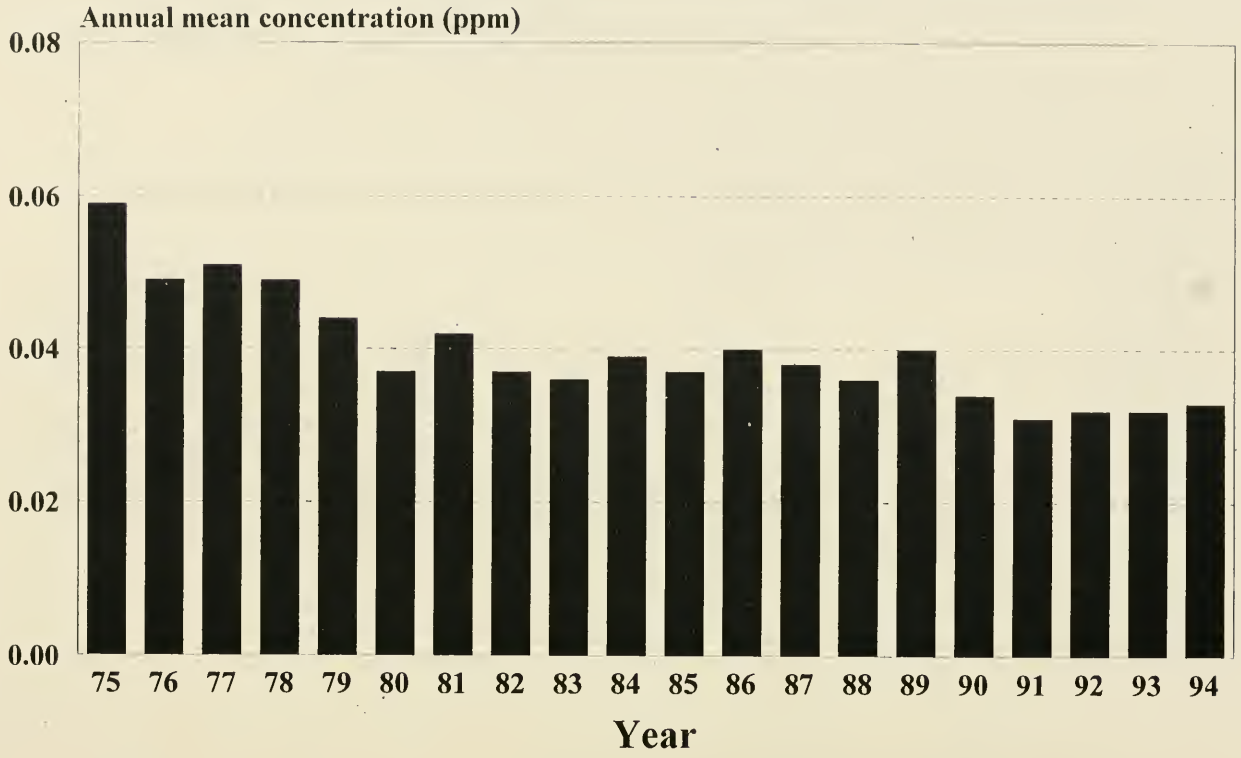
Figure E-8

Long Term Trend for NOx



Note: 15 Sites operated over 20 years

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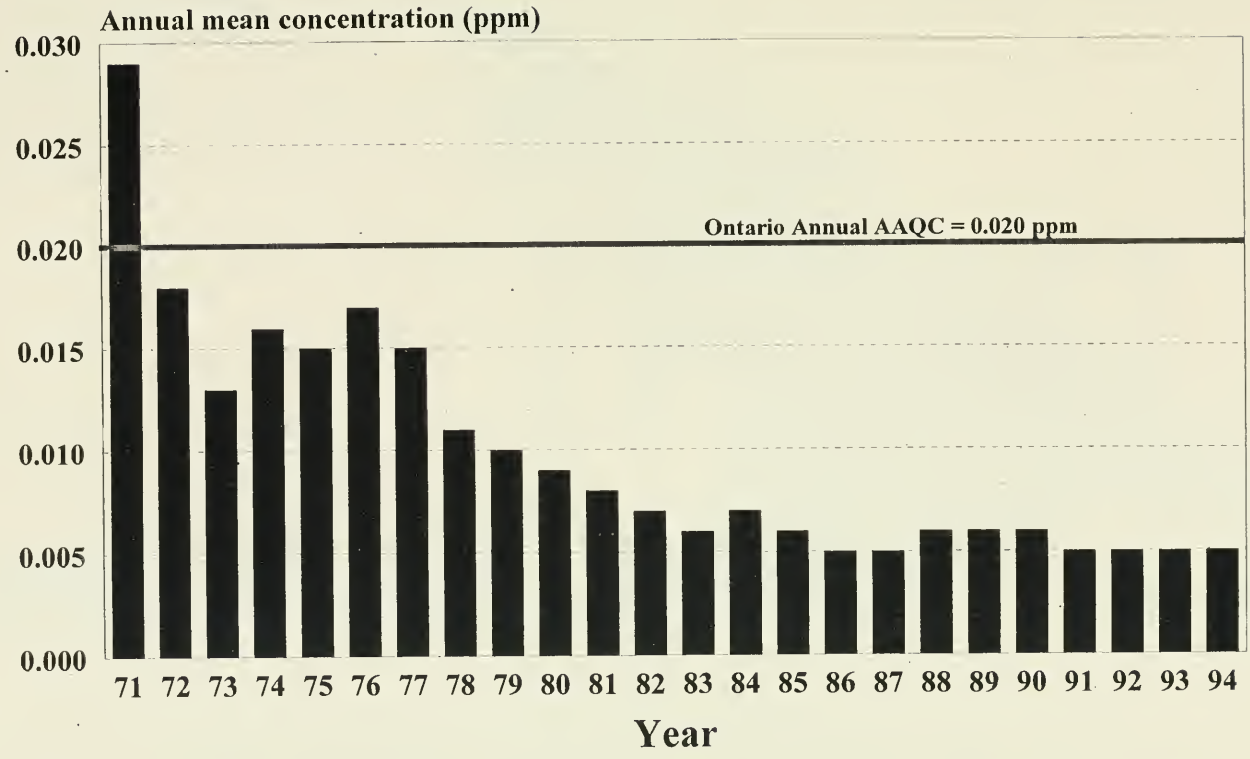
Figure E-9

Long Term Trend for SO_2



Note: 12 Sites operated over 24 years

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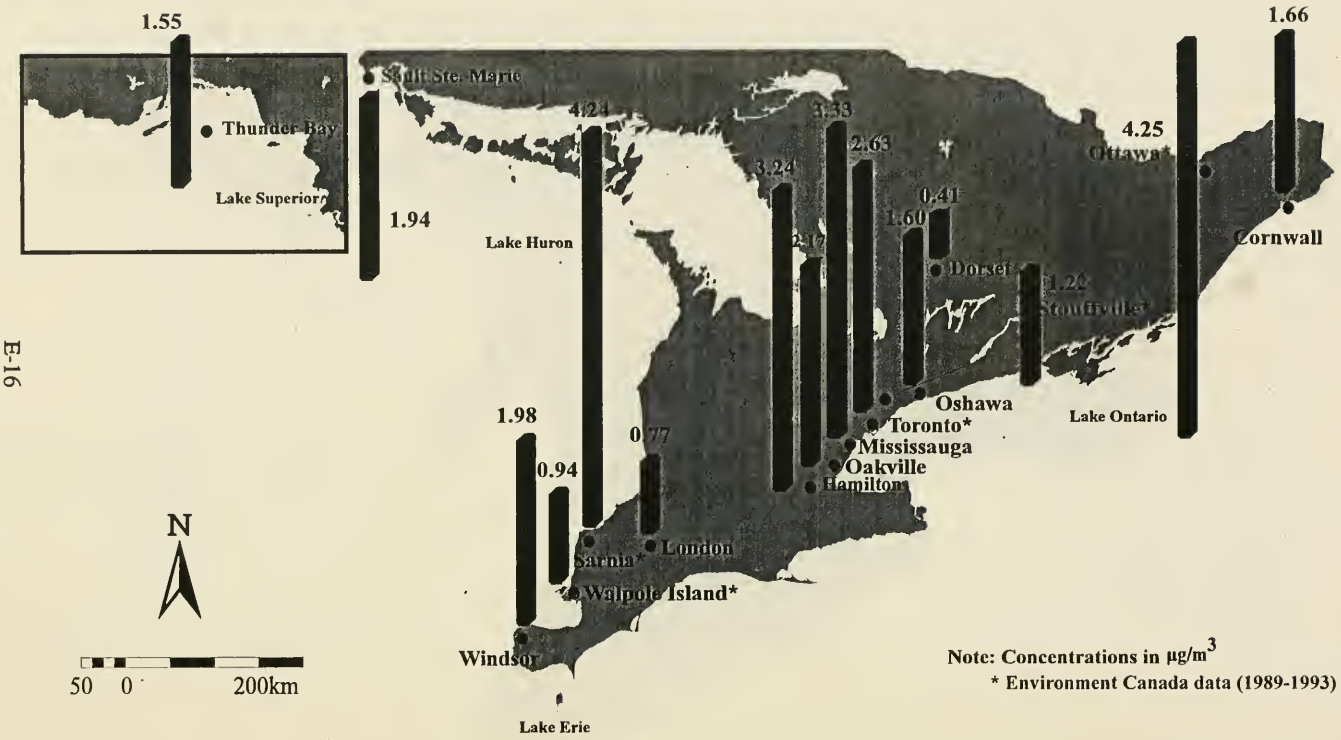
Figure E-10

Geographical Distribution of Benzene Levels Across Ontario (Average Concentrations, 1989-1994)



Science & Technology Branch

SECTION F

THE SCIENCE AND MODELLING OF THE COMPONENTS OF SMOG

SECTION F

THE SCIENCE AND MODELLING OF THE COMPONENTS OF SMOG

1. Introduction:

Within and downwind of major urban centres, air concentrations of a number of contaminants reach levels that can have negative effects on human health, vegetation and the ecosystem. Smog is a common term for mixture of harmful gaseous and particulate pollutants. Contaminants which contribute a significant part of the harmful effects of smog include ozone (O_3), inhalable particulates (i.e., particles less than or equal to 10 μm in diameter: PM10) and some volatile organic compounds (VOC's). In this section, a brief description of the chemical, physical and meteorological processes which affect concentrations of the above pollutants is provided. The development and application of models to predict the improvements in air quality due to emission reductions is described for these contaminants.

For some pollutants local emissions sources are the primary cause of high concentrations. For other compounds such as ozone, regional and global, direct or precursor emissions are a large portion of the problem. For a given contaminant, the appropriate spatial scale over which emissions must be considered depends on the following factors:

1) the lifetime of the compound in the atmosphere;
2) the photochemical production time scale for secondary pollutants (i.e., when air concentrations of a secondary pollutant are primarily the result of photochemistry as opposed to direct emissions);
3) the environmental or health end point of concern (i.e., inhalation, deposition/bioaccumulation, odour, etc); and
4) the averaging time of the environmental or health impact (i.e., acute toxics (minutes to hours), chronic/cancinogenic effects (months to years)).

Compounds can have adverse environmental impacts which may be associated with emissions from different airsheds or spatial scales. A description of global, continental/regional and urban spatial scales with example of compounds appropriate to each scale is attached as Appendix F.1.

2. Ozone:

The CCME NO_x/VOC Management Plan was initiated primarily to address the requirements for NO_x and VOC controls to mitigate problems related to ground level ozone. The phase 1 report was released in November, 1990. Working groups were established to respond to the initial objectives of the phase 1 report. The Windsor/Quebec Corridor and Southern Atlantic Region NO_x/VOC Modelling Work Group (WQC/SAR work group) was established to

develop and apply atmospheric photochemical models and thus recommend emission reduction targets required to resolve ozone problems in each region. Reports from this working group as well as all other technical working groups are to be finalized by the end of spring 1996 with the results incorporated into an overall assessment report.

Before briefly describing the modelling performed for the WQC/SAR work group, the basic photochemical production of ozone and the main removal pathways will be outlined. As indicated in the introduction, the spatial scales for which precursor emissions contribute significantly to ozone concentrations will also be presented.

2.1 Production and Depletion of Ground Level Ozone:

Ground level concentrations of ozone are the net result of a number of chemical and physical processes (i.e., transport, mixing, dry deposition). Ozone is formed primarily by the photodissociation of NO_2 (equations 1 and 2). An ozone molocule can also be removed by reacting with NO to produce NO_2 (equation 3).

1) $$NO_2 + hv \rightarrow O + NO \quad (hv \text{ is solar radiation})$$

2) $$O + O_2 + M \rightarrow O_3 + M \quad (M \text{ is air})$$

3) $$NO + O_3 \rightarrow NO_2 + O_2$$

Therefore at equilibrium, the ratio of NO_2/NO concentrations in air is the primary determinant of ozone concentrations. VOCs can affect the NO_2/NO ratio by reacting photochemically with atmospheric radicals which results in product species that oxidize NO to NO_2 (equations 4 and 5). Ozone concentrations can thus be increased by reactive VOC's.

4) $$VOC + (hv, HO, NO_3, O_3) \rightarrow \alpha RO_2$$

5) $$RO_2 + ßNO \rightarrow aNO_2 + bOH + \text{organic nitrates (e.g., PAN)}$$

The coefficients α, ß, a, b depend on the particular VOC reaction and on the VOC/NO_x ratio. The above equations decribe the basic mechanism controlling ozone concentrations but all significant reactions involving NO_x, VOCs, ozone and the atmospheric radicals must be considered in a model of atmospheric gas phase chemistry. The relative importance of NO_x and VOC emissions in determining ozone concentrations depends on the atmospheric VOC/NO_x ratio as well as the actual concentrations and the reactivities of the compounds. Organic nitrates which are also product species of equations 4 and 5, can affect human health.

Near the ground surface, ozone concentrations can be depleted by NO titration (equation 3) or by dry deposition. Daytime ozone concentrations then represent the balance between

production and depletion mechanisms. Since ozone is not produced at night, concentrations will decrease due to the depletion mechanisms. In urban areas, there are sufficient NO emissions to frequently result in surface ozone concentrations near zero at night. This occurs when wind speeds are low at night because the limited vertical mixing allows the near surface air to become depleted in ozone. At higher wind speeds, ozone from many hundreds of metres above the ground can be mixed down to the surface. Ozone concentrations would then be reduced to a minimum at night on windy days but would not fall to zero. Figure F.1 shows the typical diurnal cycle of ozone concentrations in regions with significant anthropogenic emissions of NO_x and VOCs.

There are global background ozone concentrations in the troposphere. These concentrations vary seasonally and geographically but are about 40 ppb in the northern hemisphere in the summer (CCME, 1995; Data Analysis Work Group Report, 1996). The global background would be the daytime maximum ozone concentration at ground level if there were no production due to regional or urban emissions of NO_x and VOCs. Global background ozone concentrations can have a component due to intrusion of stratospheric ozone into the upper troposphere as well as ozone produced photochemically in the troposphere. The primary precursor species which control the photochemical production of this background ozone concentration are methane and CO. These species act as slowly reacting VOCs as shown in equations 4 and 5, to oxidize some of the NO to NO_2. Emissions on a hemispheric or global scale, including a large biogenic component for methane emissions, are responsible for the photochemical component of the background ozone concentrations. Therefore, it is expected that this background ozone concentration would only be affected to a limited degree by local or regional NO_x and reactive VOC emission reductions.

Regionally, ozone concentrations can be raised above this global background concentration when precursor NO_x and VOC emissions result in net ozone production. During the warm season, regional ozone concentrations increase when a high pressure system moves very slowly through the region. The clear sky conditions promote ozone production and the slow movement of the system allows precursor species and ozone concentrations to increase over several days. Since natural VOC emissions during the warm season are quite large over most rural areas in the eastern U.S. and eastern Canada, regional VOC/NO_x ratios are high. As discussed in a recent report by the U.S. National Research Council entitled "Rethinking the Ozone Problem in Urban and Regional Air Pollution", NO_x emission reductions are most effective for regional ozone reduction because of this high VOC/NO_x ratio.

In addition to global background and regionally produced ozone, plumes from large urban areas or clusters of NO_x and VOC emission sources can affect ozone concentrations over and downwind of these areas. Since NO_x is emitted primarily as NO, local depletion of ozone during the day can occur at some locations on occasion. Further downwind, the NO_2 created by reactions 3, 4 and 5 will undergo photodissociation to produce ozone. The result is plumes with ozone concentrations increased above the regional concentration levels described above. Both VOC and NO_x emission reductions can affect the high ozone concentrations which can occur in urban plumes. Plumes from 3 urban/industrial complexes can affect

portions of southern and central Ontario. Emissions from the Detroit/Windsor/Sarnia area, the Cleveland and Ohio Valley area and the Toronto/Hamilton area can each produce plumes with elevated ozone concentrations. The impacts of these plumes on ground level ozone concentrations in southern Ontario are increased by the presence of the Great Lakes because dry deposition of ozone to water surfaces is small. In addition, limited vertical mixing rates over the lakes during the summer means that precursor NO_x and VOC emissions remain concentrated near the lake surface which allows more ozone to be produced at ground level. The small depletion rate of ozone over lake surfaces is consistent with the comparatively high annual average ozone concentrations and the large number of exceedances of Ontario's 1 hour ozone criterion at MOEE monitors at Long Point on the shore of Lake Erie and Tiverton on the shore of Lake Huron.

2.2 Modelling Ozone Concentrations:

Most of the modelling efforts currently being carried out for the Windsor/Quebec Corridor either use the Acid Deposition and Oxidant Model (ADOM) directly or use the chemical and physical components of the model. Descriptions of the components of ADOM are found in Venkatram et. al. (1988), Misra et. al. (1989), Fung et. al. (1991) and Fung et. al. (1992). The WQC/SAR Modelling Work Group Report for the 1996 NO_x/VOC assessment will include descriptions of all models used in the Phase 1 assessment as well the model evaluations and developments undertaken in this project.

Briefly, the comprehensive ADOM model includes the following five major modules:

1) transport and diffusion;
2) gas phase chemistry;
3) cloud mixing and scavenging;
4) aqueous phase chemistry and
5) dry deposition.

These modules are integrated within an Eulerian framework using a split-operator technique where the operators are run sequentially for a half time step and then run in the opposite order for the last half of the time step. The model time step is one hour with the chemistry mechanism utilizing an internal time step of 10 seconds or less. The model domains vary for the modelling efforts in the WQC/SAR working group but they start from a coarse resolution (127 km x 127 km grid size) grid covering eastern North America (see Figure F.2). Model runs on this coarse resolution domain are then used to provide boundary conditions for finer resolution model simulations over smaller domains (i.e., either 20 or 40 km across each grid cell). The vertical resolution of the model simulations also varies but ADOM normally uses 12 layers in the vertical to the 10 km level with 8 layers below 2 km. The models included in the WQC/SAR modelling efforts are described in the WQC/SAR Modelling Work Group Report. ADOM/GESIMA was the model employed by MOEE in this exercise where GESIMA is a mesoscale meteorological model used to develop meteorological fields at a 20 km grid resolution.

The WQC/SAR modelling report includes 1) a description of each modelling system; 2) an evaluation of the ADOM chemistry algorithm along with model evaluations for an ozone episode in August 1988; 3) tests on the sensitivities of the model to input emissions, boundary conditions and meteorological conditions; and 4) scenario runs to delineate the impact on ozone concentrations of various NO_x and VOC emission controls.

Evaluations of the ADOM chemical mechanism tested the sensitivity of predicted ozone concentrations to the following: the numerical solver used; the use of updated photolysis rates; to the manner in which VOC species are lumped together; and to NO_x chemistry. The conclusion was that integrating over a period of 6 days predicted maximum ozone concentrations would be larger with an improved chemical mechanism. However, the increases in ozone concentrations are not dramatic even for the long integration times used in these box model simulations.

A high ozone episode which occurred in August 1988 was used to evaluate the performance of the models. Extensive monitoring data were available for this episode because it coincided with the first Eulerian Model Evaluation Field Study (EMEFS) intensive study period. A total of about 70 ozone monitors were in the EMEFS network although the number of EMEFS sites within each of the finer resolution model domains was much smaller. The Eulerian model simulations tended to underestimate daytime maximum ozone concentrations on a regional scale (i.e., away from plumes originating from large emission source regions such as urban areas). Comparisons of modelled nighttime minima with observations varied from model to model. ADOM/GESIMA predicted these minima reasonably well but some of the other models either under or over estimated these minima. The modelled vertical mixing profile at night is the critical parameter in determining the degree of ozone depletion near the surface and the vertical extent of that depletion. Power spectral analyses of the model simulations showed that most of the Eulerian models predicted the diural cycle quite well.

Model predictions of ozone depend critically on the quality of the input data. Emissions and boundary concentrations along with meteorology are the most important input fields. The sensitivity of some of the models listed above to emission estimates and boundary concentrations were tested. The anthropogenic gridded emission inventory available for the model runs reported in the WQC/SAR Modelling Work Group Report were developed in the late 1980's for the year 1985 (some large point sources have day specific data for part of 1988). The estimates of anthropogenic VOC emissions at the time the inventory was developed are about a factor of two less than current estimates for 1985. NO_x emissions in this inventory are also lower than current 1985 estimates. The third important emission rate is natural VOC emissions. Current estimates of these biogenic emissions are also much higher than values used in the model inventory (Geron et. al., 1994). The response of the models to emission uncertainties were evaluated by comparing base case model simulations with sensitivity runs where emissions were changed over the entire model domain. The results presented below are for the change in the highest hourly ozone concentration at grid

cells across southern Ontario on each day simulated by the models (i.e., daily maximum ozone).

- Doubling anthropogenic VOC emissions resulted in daily maximum ozone concentrations increasing by 5 to 10% across most of southern Ontario with ozone concentrations increased by 15 to 25% across the greater Toronto-Hamilton area and for up to 100 km downwind.

- Increasing NO_x emissions by 30% produces daily maximum ozone concentrations which are 5 to 10% higher through southern Ontario. However in the core of large urban areas, maximum ozone concentrations either decreased by up to 5% or remained unchanged. This is due to NO depletion of ozone near large sources of NO.

- Increasing natural VOC emissions by a factor of two gave responses which varied across southern Ontario with an average increase of about 3% in ozone concentrations. In large urban areas ozone concentration increases were larger ($\approx$3 to 7%).

Predictions of daily maximum ozone concentrations are then significantly affected by the accuracy of the emission inventory. The modelled response to NO_x versus VOC emission reductions is very different. Depending on the magnitude of biogenic VOC emissions in or near urban areas, reducing anthropogenic VOCs could have an impact in lowering ozone concentration over and downwind of urban areas but VOC reductions alone are not as effective in reducing regionally elevated ozone concentrations. On the other hand, NO_x emission reductions result in comparatively large reductions in regionally elevated ozone concentrations and in plume concentrations a distance downwind from urban complexes. However, as described earlier, local depletion of ozone can occur in portions of urban areas due to titration by NO emissions. In these cases reductions in only NO_x emissions can cause some local increases in ozone. A combination of NO_x and VOC emission reductions would likely be the best strategy to reduce ozone concentrations regionally and near urban centres.

2.3 Response of Ozone Concentrations to NO_x and VOC Emission Reductions

As indicated by the emission sensitivity tests described above, the modelled response of ozone concentrations will depend on the relative NO_x versus VOC emission reductions. The modelled response also depends on where the emissions are assumed to be reduced (i.e., Ontario only, both the United States and Ontario, etc.). Ozone concentrations could be reduced by larger amounts in some regions than in others for a given emission reduction. The modelled response of ozone to emission reductions depends on meteorology and the relative importance of regionally elevated ozone to ozone produced in urban plumes thus resulting in variations in response from day to day. All of these factors as well as uncertanties in the starting emission rates used in model simulations means that estimations of the environmental benefits of NO_x/VOC emission reductions should include a range of

response (i.e., a range of possible reductions in ozone concentrations for a given percentage emission reduction).

To estimate the potential benifits of a NO_x/VOC emission control program on ozone concentrations, the global background ozone concentrations of about 40 ppb should not be considered since these emission reductions would not affect the background ozone concentration to any significant degree. The reductions in ozone concentrations would apply to the portion of the concentrations produced on the regional and urban plume scales due to anthropogenic NO_x and VOC emissions.

When the ADOM/GESIMA model was run with 25% reductions in anthropogenic NO_x and VOC emissions across the model domain, daily maximum ozone concentrations across southern Ontario were typically reduced by 5 to 9% with the reductions varying somewhat spatially and from day to day. For the controllable portion of the ozone concentrations (i.e., daily maximum ozone $>$ 40 ppb) the modelled percentage decreases were in the 10 to 18% range for a 25% reduction in both NO_x and VOCs. The maximum ozone concentration reductions were then between 40 and 70 percent as large as the NO_x and VOC emission reduction. Most model simulations which include both NO_x and VOC emission reductions show the response of daily maximum ozone concentrations above 40 ppb to be between 30 and 70 percent of the NO_x and VOC emission reduction percentages (AQIRP 1993a, AQIRP 1993b, AQIRP 1994, McLaren et. al., 1993, Possiel et. al., 1990).

To estimate the reductions in ozone concentrations due to NO_x and VOC emission reductions the following assumptions were used.

- The NO_x and VOC emissions would be reduced by similar percentages (i.e., not dominated by reductions of NO_x or VOCs).

- Only the portion of the ozone concentrations above 40 ppb would be affected by the emission reduction.

- The percentage reductions in ozone concentrations above 40 ppb was assumed to be in the range from 30 to 70 percent of the average of the NO_x and VOC emission reductions (i.e., in percent). The central estimate used was 50 percent of the average of the NO_x and VOC emission reductions.

- The emission reductions are assumed to occur across the modelling domain (i.e., emissions are reduced by the same percentage in the United States and Canada).

2.4 Influence of Emission Reductions in Ontario Versus Reductions in the United States

In addition to the model scenario with NO_x and VOC emissions reduced by 25% across the model domain, a simulation was performed with only Ontario's anthropogenic NO_x and VOC emissions reduced by 25%. The difference between these two simulations can be used to estimate the relative impact of emission reductions in the states upwind of Ontario compared to the reductions in southern Ontario ozone concentrations produced by emission reductions in Ontario only. In general, the reductions in the ozone concentrations in southwestern Ontario and in the greater Toronto-Hamilton areas were about three times as large when emissions were also reduced in the United States. Even downwind of the greater Toronto-Hamilton area reductions in ozone concentrations north of Lake Ontario were twice as large when U.S. emission reductions were included. These results indicate that for most of the population in southern Ontario much more than half of the controllable portion of the high ozone concentrations (i.e., portion of ozone above 40 ppb) are due to NO_x and VOC emissions in the United States.

2.5 Calculation of Ozone Concentration Reductions

To estimate the benefits of NO_x and VOC emission reductions, two measures of the reduction in ozone were used. The first measure used was an estimate of the percentage reduction in the average number of hours in a year that Ontario's ozone criterion of 80 ppb would be exceeded at locations in southern Ontario. To do this estimation, a range of reductions in ozone concentrations corresponding to a particular percentage reduction in NO_x and VOC emissions was calculated as described above. Observed ozone concentrations from monitoring locations across southern Ontario were then used to determine the average number of hours that Ontario's ozone criterion was exceeded and the distribution of concentrations above 80 ppb (i.e., # hours above 83, 86, 89, 92 etc ppb). Based on a five year average of observed data across southern Ontario, Figure F.3 shows the average number of hours that ozone exceeded various concentration levels at southern Ontario monitoring sites. The percentage reductions in the controllable portion of ozone concentrations were then combined with this observed data to estimate the percentage reduction in the number of hours that Ontario's ozone criterion would be exceeded.

The second measure of ozone reductions makes use of information from a CCME report (Environmental and Health Benefits of Cleaner Vehicles and Fuels) on ozone conentrations above a global background concentration of 40 ppb. In that report daily maximum ozone concentrations above 40 ppb were summed over the year at monitoring sites across Ontario. For southern Ontario an average of about 830 ppb of ozone above 40 ppb was derived from the 1990 monitoring data. Health benefits resulting from reductions in ozone concentrations were then related to this number of ppb of ozone summed over a year. The last row in Table F.1 then presents the expected reduction in this summed ppb of ozone for locations in southern Ontario. A negative number represents ozone concentration increases and thus

increases in the number of ppb of ozone above the 40 ppb global background concentration compared to 1990 levels.

These calculations were done for the following emission change scenarios:

- Existing & Readily Available Reductions with Growth: Projected emission data from Section G giving the net emission change from 1990 to 2015 including existing and readily available emission reductions combined with the expected growth were used to estimate the change expected in air quality.

- Base Case: Unreduced Emissions; Growth Only from 1990: Similarly, emission estimates from Section G for 2015 assuming that no emission reduction measures were in place after 1990 were used to calculate the deterioration in air quality due to growth of population, vehicle kilometres travelled and industry.

- 45% Reduction from 1990 NO_x and VOC Emissions: The final calculation was an estimate of the air quality improvements resulting from reducing the 1990 NO_x and VOC emissions by 45%.

The results of these calculations are given in Table F.1 below.

Table F.1
Reductions in Ozone Concentrations by 2015 Due to NO_x and VOC Emission Reductions

	Existing & Readily Available Reductions with Growth	Base Case: Unreduced Emissions; Growth Only from 1990	45% Reduction from 1990 NO_x and VOC Emissions
NO_x Emission Reduction (%)	-3	-42	45
VOC Emission Reduction (%)	-10	-41	45
Reduction in Ozone Exceedance Hours (%)	-15 (-10 → -20)	-70 (-50 → -85)	75 (55 → 90)
Reduction in Yearly Summed Ozone Concentrations above 40 ppb (ppb)	-30 (-15 → -40)	-175 (-110 → -240)	190 (125 → 250)

Note: The numbers in the table represent the expected reductions in emissions or air concentrations from current conditions (i.e., 1990). Negative numbers represent increases in emissions or air concentrations. The ranges given above come from the spatial and temporal variations in the modelled response of ozone to emission reductions as well as model uncertainty described earlier.

3. Particulate Matter (PM_{10} and $PM_{2.5}$)

As shown in the emission inventory (Section E), the coarser fraction of inhalable particulate matter (PM_{10}) comes predominantly from fugitive sources such as re-entrained dust from paved and unpaved roads, construction activities, forest and structural fires and agricultural activities. Industrial emissions can also be a significant contributor to this coarse fraction of inhalable particulate. The finer fraction is referred to as respirable particulate ($PM_{2.5}$). On average in Ontario, the respirable fraction is 50 to 60% of the total PM_{10}. Direct emissions of respirable particulates come from sources such as diesel and gasoline engines, fuel combustion, power plants, and emissions from industries. Quantitative estimates of emission rates from some of these sources, especially the fugitive sources, are not well known.

Fine particles are also formed in the atmosphere and in cloud water by chemical reactions of gaseous pollutants. Some of the sulphur dioxide (SO_2) emitted is converted to sulphate particles, while nitrates and secondary organic aerosols (SOAs) originate from NO_x and VOCs respectively. These secondary atmospheric aerosols are virtually all in the respirable size fraction (i.e., less than or equal to 2.5 μm in diameter). Observations of inhalable particulate concentrations in urban air usually show 15 to 20% are due to sulphate with about 5% due to nitrate.

Comparisons of urban versus rural data indicates that directly emitted inhalable particulate matter has a large component of the air concentrations contributed by local and urban emissions, while the secondary aerosols can be the result of precursor emissions over large regional domains. Environment Canada data (Brookes, 1994) show urban PM_{10} concentrations to be about two times rural concentrations. Since the rural data also include local contributions, long range transport can account for less than half of the urban inhalable particulate concentrations. The same data set shows that rural sulphate concentrations are 80 to 95% of the urban sulphate concentrations while nitrates in rural air are about 30 to 60% of urban concentrations. These results indicate that region wide emissions must be considered for secondary particulate formation, especially in the case of sulphates.

To directly model the effects of emission reductions on inhalable particulate concentrations the following would be required:

1) Region wide emissions of precursor gas species (i.e., SO_2, NO_x and VOCs) incorporated into a photochemical model which includes an aerosol module.

2) Region wide emissions of directly emitted inhalable particulate with a finer spatial resolution over urban areas to allow modelling of localized contributions to the air concentrations.

Modelling over a large region would be needed to estimate the long range transport contributions to air concentrations but nested high resolution modelling would also be required to calculate concentrations over urban areas. The major difficulty in performing

such calculations is developing a reliable inventory of directly emitted inhalable particulates. As shown in the emission inventory (Section E), current estimates have fugitive sources such as road dust and construction activities accounting for the majority of both the coarse and finer fractions of the inhalable particulate emissions. In the CCME report on the Environmental and Health Benefits of Cleaner Vehicles and Fuels, source-receptor modelling results from studies in Canada and the United States were examined. These studies consistently found the percentage contribution of direct tailpipe PM_{10} and especially $PM_{2.5}$ to be much higher than indicated by current emission inventory estimates. These source-receptor studies usually show that fugitive dust sources are important for the coarser fraction of inhalable particulate but are not the major contributor to $PM_{2.5}$. For the CCME study, the results from source-receptor modelling in a number of Canadian cities were used to estimate improvement due to reductions in tailpipe inhalable particulate emissions. For Ontario cities, the CCME report attributed 10% of the observed PM_{10} concentrations to transportation sources. For southern Ontario urban centres, the CCME reports' central estimate for the reduction in PM_{10} due to reductions in direct tailpipe inhalable particulate emissions (resulting from lower sulphur concentration in fuel) was about 0.7 $\mu g/m^3$ for the daily average. This is the reduction in PM_{10} averaged over a year.

Reductions in the secondary formation of inhalable particulates can be estimated by assuming the percentage reductions in air concentrations for these species are proportional to the percentage reductions in the precursor species (i.e., SO_2, NO_x and VOCs) where the precursor emissions are reduced across the entire region. Observed air concentrations for sulphates and nitrates along with estimated concentrations for secondary organic aerosols can then be used to calculate improvements in inhalable particulate concentrations. Using this methodology, Table F.2 below gives expected reductions in PM_{10} air concentrations in Ontario urban centres. The percentage changes in NO_x and VOC emissions are as presented in Table F.1. The current urban air concentrations used to derive Table F.2 were:

Nitrates: 1.5 $\mu g/m^3$ in southern Ontario and 1 $\mu g/m^3$ in northern Ontario

SOAs (estimated using data from CCME report and Bovar-Concord GVRD report):
1 $\mu g/m^3$ in southern Ontario and $\approx$ 0.3 $\mu g/m^3$ in northern Ontario.

Table F.2

Reductions in IP Concentrations by 2015 Due to NO_x and VOC Emission Reduction

	Existing & Readily Available Reductions with Growth	Base Case: Unreduced Emissions; Growth Only from 1990	45% Reduction from 1990 NO_x and VOC Emissions
Nitrate Concentration Reductions ($\mu g/m^3$)	South: -0.06 North: -0.04	South: -0.6 North: -0.4	South: 0.6 North: 0.4
Secondary Organic Aerosol Concentration Reductions ($\mu g/m^3$)	South: -0.1 North: -0.03	South: -0.4 North: -0.15	South: 0.4 North: 0.15

Note: The numbers in the table represent the expected reductions in air concentrations from current conditions (i.e., 1990). Negative numbers correspond to a deterioration in air quality.

A 40% reduction in SO_2 emissions, based on requirements in the U.S. Clean Air Act and emission reductions in Ontario, would result in about 2 $\mu g/m^3$ reduction in inhalable particulate for southern Ontario urban centres and about a 1 $\mu g/m^3$ reduction for northern Ontario urban centres.

Appendix F.1
Spatial Scales or Airsheds:

Global: This refers to compounds with very long half lives (i.e., months or years) or to background concentrations of photochemically active compounds. Examples of compounds for which global scale emissions are the concern are CO_2, CFC's and carbon tetrachloride. Tropospheric ozone is an example of a compound with a shorter half life but continual production results in a significant global background concentration.

Continental/Regional: The end points for compounds where continental/regional emissions are the concern could be damages due to deposition/bioacumulation, inhalation or environmental impacts on vegetation, forests or watersheds. Many heavy metals and persistent organic pollutants (POP's) such as dioxins, furans, pesticides, herbicides, PCB's, PAH's etc have at least a regional scale over which emissions must be considered when assessing problems caused by deposition or inhalation exposure to these contaminants. In the case of acid deposition, precursor emissions of nitrogen oxides (NO_x) and sulphur dioxide (SO_2) over the northeastern part of North America must be considered to address this problem. In addition to the global background ozone in the troposphere, ozone can be photochemically produced on a regional scale due to precursor emissions of NO_x and VOC's. The spatial scale over which emissions affect downwind concentrations of ozone varies with meteorology, the distribution of emission sources and with land surface characteristics. Widespread ozone episodes can involve emissions from across the north eastern part of North

America. On the other hand, plumes from urban areas or industrial source clusters can result in elevated ozone concentrations over distances of tens to hundreds of kilometres.

Another regional air concern is the effect of acidic aerosols on human health. There is a significant regional component to the air concentrations of sulphates and nitrates (i.e., both are secondary particulates). An example of a photochemically active compound where inhalation is the pathway of concern is formaldehyde. Since rural concentrations of this contaminant are a significant fraction of urban concentrations, photochemistry and emissions on a regional scale are important.

Urban: Compounds with acute effects and widely distributed emission sources could be considered to have an urban spatial scale. Examples compounds are CO, NO_2, SO_2 and fine particulate. These compounds can all have human health impacts for averaging times of 1 to 24 hours. The density of emissions in the urban areas for these contaminants results in concentrations which are usually much larger than rural concentrations. For other contaminants where regional emissions are a concern, the urban area can have elevated concentrations when local emissions are added to regional, continental or global concentrations transported into the area. This urban contribution can also occur for secondary pollutants such as acid aerosols, when slow moving meteorological systems allow time for photochemical formation of the contaminant.

To model the environmental benefits of emission reductions, all spatial scales which contribute significantly to air concentrations must be considered.

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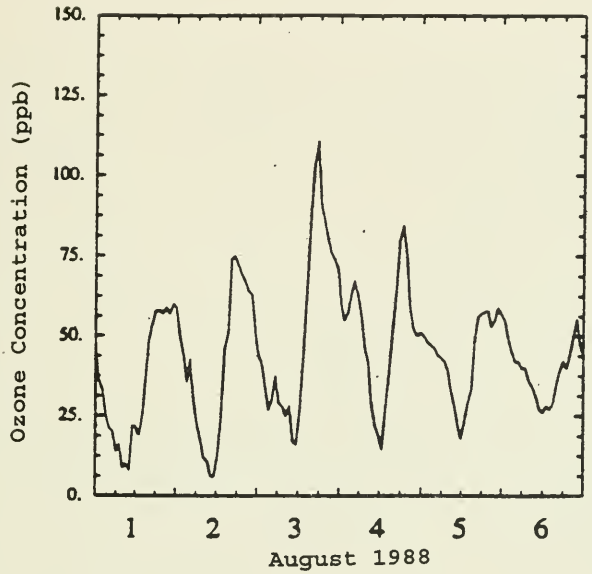
Figure F.1
Typical Diural Cycle of Ozone Concentrations



Note: Concentrations are at their minima in the early morning (i.e., 6 to 10 am).

Figure F.2
Eastern North America Modelling Domain

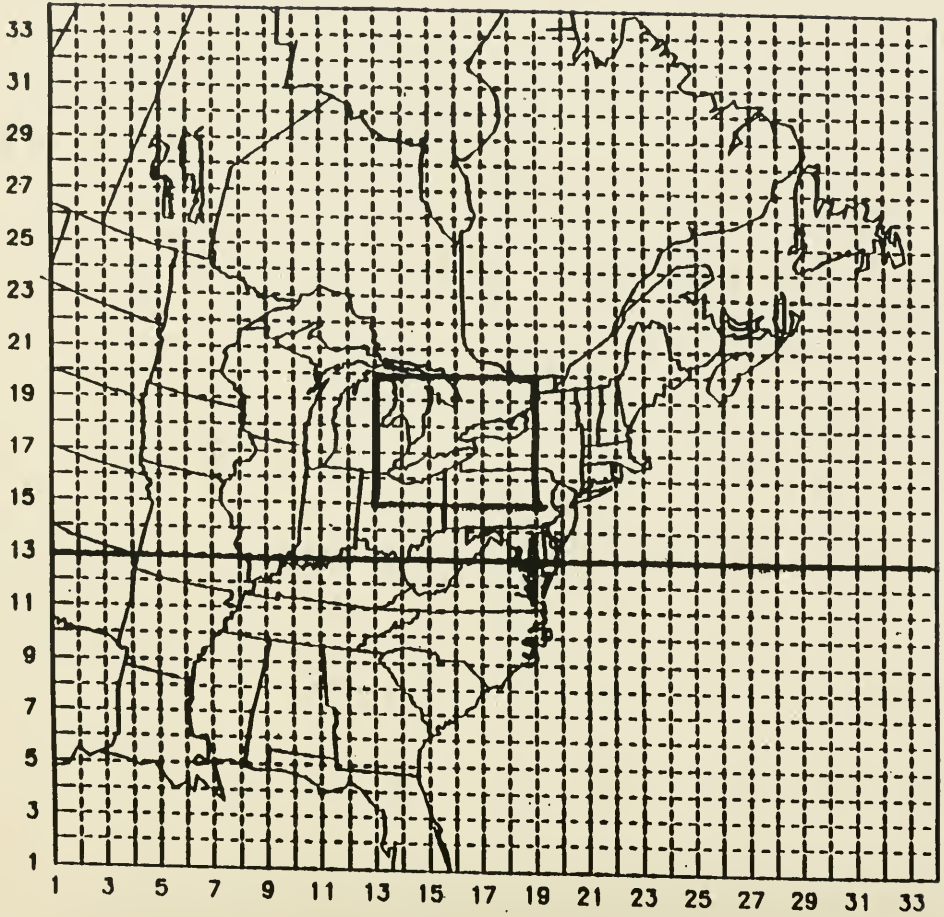
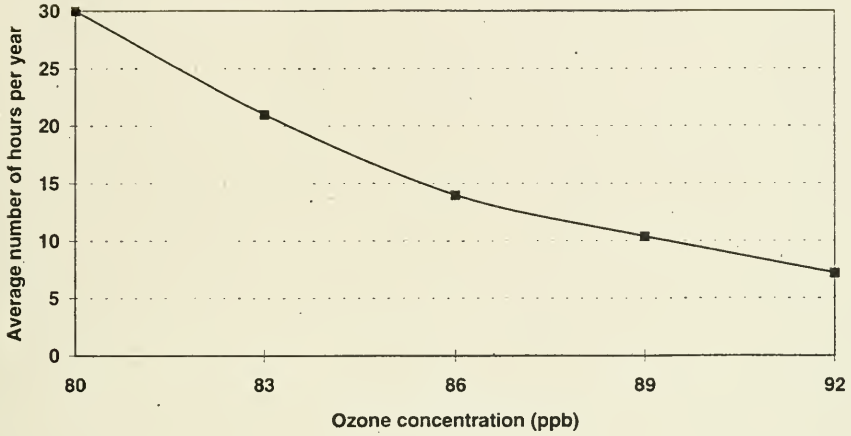


Figure F.3 :
Frequency of High Ozone Concentrations



Note: Observed concentrations for the period from 1990 to 1994 at 19 monitoring locations across southwestern and south cental Ontario were used to determine the average number of hours that each station exceeded 80, 83, 86, 89 and 92 ppb. Approximately 75% of the hours in which Ontario's ozone criterion (80 ppb) was exceeded had concentrations of 92 ppb or less.

SECTION G

REDUCTION ACTIVITIES AND STRATEGIC OPPORTUNITIES

SECTION G

REDUCTION ACTIVITIES AND STRATEGIC OPPORTUNITIES

1.0 INTRODUCTION

This section of the supporting document is intended to summarize emissions of NOx and VOCs for the years between 1985 and 2015; provide estimates and descriptions of emission reductions for EXISTING COMMITMENTS and for "READILY AVAILABLE" FUTURE OPPORTUNITIES. Baseline emission estimates are summarized in section 2. and details of Existing Commitments and Readily Available Opportunities are summarized in section 3 (Tables G.3.1 to G.3.4). Notes on the derivation of these estimates are provided in sections 4 and 5. The following table provides a summary of the assumptions and information sources used to derive the baseline emissions estimates.

Definitions:	
- Existing Commitments	Existing Commitments are defined as published guidelines, regulations, memoranda of understanding, or documented voluntary commitments that were made on or before March 1996. Reductions from Existing Commitments will be realized between 1997 and 2005.
- "Readily Available" Future Opportunities	"Readily Available" Future Opportunities will be defined as activities that are presently under development (i.e., Canadian Council of Ministers of the Environment NOx/VOCs Management Plan initiatives; MOUs presently under negotiation, etc.) and will be realized by the year 2005.
Sources of Emission Information Used to Derive Baseline Emission Estimates and Reductions	
- Estimates for 1985 Emissions:	Draft MOEE document, "Fast Reference Emission Document, Version 3, January 1996";
- Estimates for 1990 to 2010 Emissions:	National Emissions Inventory and Projections Task Group (NEIPTG; representatives of provincial and federal governments) document, "NEIPTG Consensus forecast, Version 2.1, March 1996";
- Estimates for 2015 Emissions:	Extrapolation of 2010 emission estimates from NEIPTG.
- Transportation Source Emission Reduction Activities:	Existing (1988 and 1994-96) Transportation Emission Reductions: Environment Canada runs of MOBILE 5C program, completed in January 1995, that incorporates vehicle emission standards from 1988 and 1994-96; Future (post 1996) Transportation Emission Reductions: Draft MOEE Document, "Projected Emissions from Light Duty Gasoline Vehicles, February 1996" that includes emission reduction projections for Light-Duty Vehicles (only) under a variety of vehicle emission standard and vehicle inspection and maintenance scenarios;
- Ind./Comm. Sector Emission Reduction Activities:	Existing and "Readily Available" Future Activities: Input from MOEE staff (Program Development and Science & Technology branch) for the various initiatives and reference to various CCME NOx/VOCs Management Plan Documents.
Baseline Year: (for comparison of Existing and "Readily Available" Future reduction activities/estimates)	1990

Note: Information regarding PM_{10} is under development and is not presently available.

2.0 NOTES for BASELINE EMISSION ESTIMATES

Two sets of baseline emission estimates/projections are provided. Table G.2.1 - No Reduction Activities after 1996 and Table G.2.2 - No Reduction Activities after 1990, where post-1990 emission reductions for Light and Heavy Duty On-Road Vehicles; and post-1990 NOx emission reductions for Ontario Hydro and INCO are added back into the baseline emissions (this provides a scenario of projected emissions if no reduction activities had occurred after 1990). The emission projections in Table G.2.1 include reductions from Ontario Hydro and INCO because they have already been realized. However, emission reduction from other existing commitments and readily available opportunities are not included in the baseline emission estimates (see Tables G.3.1 to Table G.3.4 in section 3 for a summary of the reduction activities).

In general, the emission estimates for 1985 are from the latest draft (Version 3, 1996) of the Ontario Ministry of Environment and Energy's (MOEE) Fast Reference Emission Document (FRED). The BASELINE emission estimates/projections in Table G.2.1 for 1995-2010 are derived from the National Emission Inventory and Projections Task Group (NEIPTG) - NEIPTG Consensus National Base Case Forecast, Version 2.1, March 1996 (with an update supplied by Environment Canada to the MOEE in April 1996). Emission projections, in Table G.2.1, for 2015 are extrapolations of the 2010 emission estimates from the NEIPTG document.

Details of Existing Commitments and Readily Available Opportunities are summarized in section 3 (Tables G.3.1 to G.3.4). Notes on the derivation of these estimates are provided in sections 4 and 5.

The upper lines in Figures 3 and 4 of "Towards a Smog Plan for Ontario" document were derived by using the Baseline Emission Estimates (Table G.2.1) and subtracting the emission reductions from the Existing Commitments and Readily Available Opportunities (Tables G.3.1 to G.3.4).

Table G.2.1 Baseline Emission Estimates (No New Reduction Activities after 1996)

Sector	Baseline Emission (Kilotonnes/year)						
	1985	1990	1995	2000	2005	2010	2015
NOx Emissions							
TRANSPORTATION SECTOR:							
Cars	135	114	92	81	81	86	91
Light Duty Trucks - Gasoline	34	32	32	30	42	62	66
Light Duty Trucks - Diesel	1	1	1	1	2	1	1
Heavy Duty Trucks - Gasoline	3	3	2	2	4	1	1
Heavy Duty Trucks - Diesel	111	117	91	74	59	55	51
Off-Road Vehicles - Gasoline	9	11	11	12	12	13	14
Off-Road Vehicles - Diesel	92	104	112	131	138	148	159
Other (marine, aircraft)	20	19	18	19	22	23	24
Sub-Total:	**405**	**401**	**359**	**350**	**360**	**389**	**407**
ONTARIO HYDRO	**95**	**77**	**35**	**58**	**58**	**58**	**58**
IND./COMM./RESIDENTIAL SECTOR:							
Copper and Nickel Production	49	53	10	19	26	32	39
Iron and Steel Production	22	22	24	28	31	33	35
Petroleum Refining	14	14	15	18	20	21	22
Pulp and Paper Industry	10	9	10	12	13	15	17
Cement and Concrete Manufacture	9	10	8	10	12	14	16
Other Industrial	34	46	49	57	64	71	79
Residential	16	16	16	17	17	16	15
Commercial and Institutional	9	8	10	11	11	12	13
Miscellaneous	3	3	3	4	4	4	4
Sub-Total:	**166**	**181**	**145**	**176**	**198**	**218**	**240**
Total:	**666**	**659**	**539**	**584**	**616**	**665**	**705**
VOC Emissions							
TRANSPORTATION SECTOR:							
Cars	198	166	116	104	105	111	117
Light Duty Trucks - Gasoline	54	44	39	38	39	42	45
Light Duty Trucks - Diesel	-	-	-	-	-	-	-
Heavy Duty Trucks - Gasoline	5	3	2	1	3	3	3
Heavy Duty Trucks - Diesel	14	13	12	11	11	12	13
Off-Road Vehicles - Gasoline	28	35	39	31	30	34	39
Other	25	26	25	27	29	31	33
Sub-Total:	**324**	**287**	**233**	**212**	**217**	**233**	**250**
IND./COMM./RESIDENTIAL SECTOR:							
Solvent Use	115	124	134	142	149	155	161
Surface Coatings	111	122	137	146	156	167	179
Fuel Wood Combustion	107	115	106	105	105	105	105
Fuel Marketing	34	35	35	37	40	43	46
Petroleum Refining	25	35	36	40	44	49	55
Iron and Steel Production	30	25	31	36	42	46	50
Petrochemicals	10	12	13	16	19	22	25
Pulp and Paper Industry	8	8	8	10	11	12	13
Dry Cleaning	5	6	6	7	7	7	7
Other Industrial	72	76	81	94	108	122	138
Miscellaneous	21	22	24	29	29	29	29
Residential - Fuel Combustion	1	1	1	1	1	1	1
Sub-Total:	**539**	**581**	**612**	**663**	**711**	**758**	**809**
Total:	**863**	**868**	**845**	**875**	**928**	**991**	**1059**

Table G.2.2 Baseline Emission Estimates (No New Reduction Activities after 1990)

Sector	Baseline Emission (Kilotonnes/year)						
	1985	1990	1995	2000	2005	2010	2015
NOx Emissions							
TRANSPORTATION SECTOR:							
Cars	135	114	116	125	122	118	125
Light Duty Trucks - Gasoline	34	32	40	46	63	85	90
Light Duty Trucks - Diesel	1	1	2	2	3	2	2
Heavy Duty Trucks - Gasoline	3	3	3	4	10	3	3
Heavy Duty Trucks - Diesel	111	117	134	145	150	168	156
Off-Road Vehicles - Gasoline	9	11	11	12	12	13	14
Off-Road Vehicles - Diesel	92	104	112	131	138	148	159
Other (marine, aircraft)	20	19	18	19	22	23	24
Sub-Total:	**405**	**401**	**436**	**484**	**520**	**560**	**573**
ONTARIO HYDRO	**95**	**77**	**35**	**58**	**77**	**77**	**77**
IND./COMM./RESIDENTIAL SECTOR:							
Copper and Nickel Production	49	53	53	62	69	75	82
Iron and Steel Production	22	22	24	28	31	33	35
Petroleum Refining	14	14	15	18	20	21	22
Pulp and Paper Industry	10	9	10	12	13	15	17
Cement and Concrete Manufacture	9	10	8	10	12	14	16
Other Industrial	34	46	49	57	64	71	79
Residential	16	16	16	17	17	16	15
Commercial and Institutional	9	8	10	11	11	12	13
Miscellaneous	3	3	3	4	4	4	4
Sub-Total:	**166**	**181**	**188**	**219**	**241**	**261**	**283**
Total:	**666**	**659**	**659**	**761**	**838**	**898**	**933**
VOC Emissions							
TRANSPORTATION SECTOR:							
Cars	198	166	169	181	196	212	223
Light Duty Trucks - Gasoline	54	44	57	66	73	80	86
Light Duty Trucks - Diesel	-	-	-	-	-	-	-
Heavy Duty Trucks - Gasoline	5	3	3	2	4	5	5
Heavy Duty Trucks - Diesel	14	13	15	17	17	18	20
Off-Road Vehicles - Gasoline	28	35	39	31	30	34	39
Other	25	26	25	27	29	31	33
Sub-Total:	**324**	**287**	**308**	**324**	**349**	**380**	**406**
IND./COMM./RESIDENTIAL SECTOR:							
Solvent Use	115	124	134	142	149	155	161
Surface Coatings	111	122	137	146	156	167	179
Fuel Wood Combustion	107	115	106	105	105	105	105
Fuel Marketing	34	35	35	37	40	43	46
Petroleum Refining	25	35	36	40	44	49	55
Iron and Steel Production	30	25	31	36	42	46	50
Petrochemicals	10	12	13	16	19	22	25
Pulp and Paper Industry	8	8	8	10	11	12	13
Dry Cleaning	5	6	6	7	7	7	7
Other Industrial	72	76	81	94	108	122	138
Miscellaneous	21	22	24	29	29	29	29
Residential - Fuel Combustion	1	1	1	1	1	1	1
Sub-Total:	**539**	**581**	**612**	**663**	**711**	**758**	**809**
Total:	**863**	**868**	**920**	**987**	**1060**	**1138**	**1215**

3.0 SUMMARY OF EMISSION REDUCTION ACTIVITIES

Details of Existing Commitments and Readily Available Opportunities are summarized in the following four tables (Tables G.3.1 to G.3.4). The specific sector initiatives and associated reductions are shown. Notes on the derivation of these estimates are provided in sections 4 and 5.

Table G.3.1 Existing Commitments - NOx Emission Reductions (1990 to 2015)

Sector	Baseline (1990) NOx Emissions (Kilotonnes)	Projected (2015) NOx Emissions No New Reduction Efforts after 1996 (Kilotonnes)	NOx Emission Reduction Measure	Estimated -Gross- Reductions from 1990 (Kilotonnes)	Estimated Cost ($/Tonne)	Mechanism	Year Realized
Existing Commitments - NOx Emission Reductions							
Transportation							
Cars	114	91	Vehicle Emission Stds - 1988 and 1994-96	incl. in 2015 project.		Regulation & Voluntary	1988-2015
Light Duty Trucks - Gasoline	32	66	Vehicle Emission Stds - 1988 and 1994-96	-			
Light Duty Trucks - Diesel	1	1	Vehicle Emission Stds - 1988 and 1994-96	-			
Heavy Duty Trucks - Gasoline	3	1	Vehicle Emission Stds - U.S.	-			
Heavy Duty Trucks - Diesel	117	51	Vehicle Emission Stds - U.S.	incl. in 2015 project.		MOU	
Off-Road Vehicles - Gasoline	11	14					
Off-Road Vehicles - Diesel	104	159					
Other (marine, aircraft)	19	24					
Sub-Total:	401	407					
Ontario Hydro	77	58	Ontario Hydro Commitment - 1991	19	$1400-4200	Voluntary/ERT	2000
Ind/Comm/Resid.							
Copper and Nickel Production	53	39	INCO Commitment (Fuel Switching) - 1991	43		Voluntary	1991
Iron and Steel Production	22	35					
Petroleum Refining	14	22					
Pulp and Paper Industry	9	17					
Cement and Concrete Manuf.	10	16					
Other Industrial	46	79	Combustion Turbine Guideline - March/94	incl. in 2015 project.	$100-200	CofA Cond.	1995-2015
			Energy Efficiency Initiatives	4.5	$0	Voluntary	2000-2015
			Can. Chemical Prod. Assoc. Initiatives	2		Voluntary	2000-2015
Residential	16	15					
Commercial and Institutional	8	13	Energy Efficiency Initiatives	1.5	$0	Regulation (new perf std)	2000-2015
Miscellaneous	3	4					
Sub-Total:	181	240					
Totals:	659	705		70			

Table G.3.2 Existing Commitments - VOC Emission Reductions (1990 to 2015)

Sector	Baseline (1990) VOC Emissions (Kilotonnes)	Projected (2015) VOC Emissions No New Reduction Efforts after 1996 (Kilotonnes)	VOC Emission Reduction Measure	Estimated -Gross- Reductions from 1990 (Kilotonnes)	Estimated Cost ($/Tonne)	Mechanism	Year Realized
Existing Commitments - VOC Emission Reductions							
Transportation							
Cars	166	117	Vehicle Emission Stds - 1988 and 1994-96	incl. in 2015 project.		Regulation	1988-2015
Light Duty Trucks - Gasoline	44	45	Vehicle Emission Stds - 1988 and 1994-96	-			
Light Duty Trucks - Diesel	-	-	Vehicle Emission Stds - 1988 and 1994-96	-			
Heavy Duty Trucks - Gasoline	3	3	Vehicle Emission Stds - U.S.	-			
Heavy Duty Trucks - Diesel	13	13	Vehicle Emission Stds - U.S.	incl. in 2015 project.			
Off-Road Vehicles - Gasoline	35	39					
Other (marine, aircraft)	26	33					
Sub-Total:	287	250					
Ind/Comm/Resid.							
Solvent Use	124	161	Consumer Products (V103)	7		Voluntary	1997
			Cleaning/Degreasing (V309/V614)	4		Voluntary	2005
			Adhesives/Sealants (V102)	0.7		Voluntary	1997
Surface Coatings	122	179	Consumer Surface Coating (V101)	17		Voluntary	1997
			Ind/Comm Initiatives (V307/V612)	6	$38000 - 57000	Voluntary	2005
Fuel Wood Combustion	115	105					
Fuel Marketing	35	46	Vap. Recovery at Gas distribution Centers	19		Regulation	1995-1998
Petroleum Refining	35	55					
Iron and Steel Production	25	50					
Petrochemicals	12	25	CCPA - NERM Program	7		Voluntary	1997
Pulp and Paper Industry	8	13					
Dry Cleaning	6	7	Dry Cleaning (V310/V615)	0.9		Voluntary	1997
Other Industrial	76	138					
Miscellaneous	22	29					
Residential - Fuel Combustion	1	1					
Sub-Total:	581	809					
Totals:	868	1059		62			

Table G.3.3 "Readily Available" Opportunities - NOx Emission Reductions (1990 to 2015)

Sector	Baseline (1990) NOx Emissions (Kilotonnes)	Projected (2015) NOx Emissions No New Reduction Efforts after 1996 (Kilotonnes)	NOx Emission Reduction Measure	Estimated -Gross- Reductions from 1990 (Kilotonnes)	Estimated Cost ($/Tonne)	Mechanism	Year Realized
Existing Commitments - NOx Emission Reductions							
Transportation							
Cars	114	91	Light Duty Vehicle Emission Stds - post 1996	4		Regulation	2005
Light Duty Trucks - Gasoline	32	66	Light Duty Vehicle Emission Stds - post 1996	incl in above			(>60% by 2000)
Light Duty Trucks - Diesel	1	1					
Heavy Duty Trucks - Gasoline	3	1					
Heavy Duty Trucks - Diesel	117	51					
Off-Road Vehicles - Gasoline	11	14					
Off-Road Vehicles - Diesel	104	159					
Other (marine, aircraft)	19	24					
Sub-Total:	401	407					
Ontario Hydro	77	58					
Ind/Comm/Resid.							
Copper and Nickel Production	53	39					
Iron and Steel Production	22	35	Vol. Reduction Targets for Large Facilities	8	$0-400	Voluntary	2015
Petroleum Refining	14	22	Vol. Reduction Targets for Large Facilities	3	$0-400	Voluntary	2015
Pulp and Paper Industry	9	17					
Cement and Concrete Manuf.	10	16	Vol. Reduction Targets for Large Facilities	3	$0-4200	Voluntary	2015
Other Industrial	46	79	Guidelines for New, large Boilers	1	$300-400	CofA Cond.	2015
			Boiler Inspection & Maintenance	0.1	$0	Voluntary	2015
Residential	16	15					
Commercial and Institutional	8	13	Design or Performance Standards	1	$300-400	CSA-type Std.	2015
			Boiler Inspection & Maintenance	0.1	$0	Voluntary	2015
Miscellaneous	3	4					
Sub-Total:	181	240					
Totals:	659	705		20			

Note: i) The above emission reductions do NOT include reductions from a mandatory I&M program (further 16 kilotonnes of NOx emission reductions).

Table G.3.4 "Readily Available" Opportunities - VOC Emission Reductions (1990 to 2015)

Sector	Baseline (1990) VOC Emissions (Kilotonnes)	Projected (2015) VOC Emissions No New Reduction Efforts after 1996 (Kilotonnes)	VOC Emission Reduction Measure	Estimated -Gross- Reductions from 1990 (Kilotonnes)	Estimated Cost ($/Tonne)	Mechanism	Year Realized
Existing Commitments - VOC Emission Reductions							
Transportation							
Cars	166	117	Light Duty Vehicle Emission Stds - post 1996	3		Regulation	2005
Light Duty Trucks - Gasoline	44	45	Light Duty Vehicle Emission Stds - post 1996	incl in above			
Light Duty Trucks - Diesel	-	-	Fuel - Reid Vapour Pressure	18		Regulation	2005
Heavy Duty Trucks - Gasoline	3	3					
Heavy Duty Trucks - Diesel	13	13					
Off-Road Vehicles - Gasoline	35	39					
Other (marine, aircraft)	26	33					
Sub-Total:	287	250					
Ind/Comm/Resid.							
Solvent Use	124	161	Printing Sector Initiatives (V308/V613)	6	$300 - 4000	Voluntary	2005
Surface Coatings	122	179	Ind/Comm Initiatives (V307/V612) - Future	10		Voluntary	2005
			Consumer Surface Coating (V101) - Future	5		Voluntary	2005
Fuel Wood Combustion	115	105					
Fuel Marketing	35	46					
Petroleum Refining	35	55	Petroleum Refining Fugitives Initiative	?		Voluntary	2005
Iron and Steel Production	25	50					
Petrochemicals	12	25					
Pulp and Paper Industry	8	13					
Dry Cleaning	6	7					
Other Industrial	76	138					
Miscellaneous	22	29					
Residential - Fuel Combustion	1	1					
Sub-Total:	581	809					
Totals:	868	1059		42			

Note: i) The upper lines in Figures 3 and 4 of Towards a Smog Plan for Ontario document were derived by using the Baseline Emission Estimates (Table D.1.1) and subtracting the emission reductions from the Existing Commitments and Readily Available Opportunities.

ii) The above emission reductions do NOT include reductions from a mandatory I&M program (further 40 kilotonnes of VOC emission reductions).

4.0 EXISTING and COMMITTED EMISSION REDUCTIONS

4.1 Notes for Existing and Committed NOx Emission Reductions/Costs

This section provides technical details on the existing and committed NOx reduction initiatives summarized in Tables G.3.1 to G.3.4.

4.1.1 Vehicle Emission Standards - 1988 and 1994-96

NOx and VOC emissions from transportation sources ranging from Light-Duty Gasoline Vehicles to Heavy-Duty Diesel Vehicles to Motorcycles can be estimated using a software program identified as MOBILE 5C model.

Net NOx and VOC emission reduction projections (for any year relative to 1990), from the impact of new light-duty vehicle emission standards implemented in 1988 and 1994-96 and from new U.S. heavy-duty vehicle emission standards, can be calculated from the difference in emissions from any year to 1990 emissions (see Table G.2.1 - Baseline Emission Estimates - No Reduction Activities after 1996). The estimated growth in NOx and VOC emissions for the transportation sector can be estimated by multiplying the fractional increase in vehicle-kilometers travelled, relative to 1990, by the 1990 baseline emission estimates. Gross Emission Reductions, from the above noted activities, can then be estimated by adding the Net Emission Reductions to the Estimated Growth in Emissions for any year relative to 1990. Tables 4.1.1 provide a summary of estimated growth, net emission reductions and gross emission reductions. Table 4.1.2 provides a summary of expected growth in vehicle kilometers travelled for Ontario between 1985 and 2010.

Table 4.1.1 Estimated Growth and Emission Reductions (Light and Heavy Duty Vehicles)

YEAR	Light Duty On-Road Vehicles (Kilotonnes)						Heavy Duty On-Road Vehicles (Kilotonnes)					
	Growth		Net Reductions		Gross Reductions		Growth		Net Reductions		Gross Reductions	
	NOx	VOCs	NOx	VOCs	NOx	VOCs	NOx	VOCs	NOx	VOCs	NOx	VOCs
1995	11	16	22	55	33	71	17	2	27	2	44	4
2000	26	37	35	68	61	105	29	3	44	4	73	7
2005	41	59	22	66	63	125	40	5	57	2	97	7
2010	58	82	- 2	57	56	139	51	7	64	1	115	8

Notes: i) Growth = (Vehicle KM_{year}/Vehicle KM_{1990} - 1) x NOx_{1990}

ii) Net Reductions = (NOx_{1990} - NOx_{year})

iii) Gross Reductions = (Growth + Net Reductions)

Table 4.1.2 Vehicle Kilometers Travelled for Ontario from MOBILE 5C

YEAR	Annual Vehicle Kilometers Travelled (Million Kilometers)				
	Passenger Car	Light Duty Trucks	Heavy Duty Vehicles	Others	Total
1985	64,472	15,730	7,974	4,625	92,801
1986	66,842	16,453	8,340	4,766	96,401
1987	69,338	17,363	8,802	4,913	100,416
1988	72,096	18,410	9,333	5,078	104,916
1989	74,051	18,802	9,531	5,185	107,569
1990	75,108	21,064	9,934	5,254	111,360
1991	74,325	19,316	10,188	5,203	109,032
1992	76,521	21,750	10,452	5,346	114,069
1993	77,286	22,728	10,725	5,396	116,135
1994	78,059	23,750	11,008	5,447	118,264
1995	78,839	24,819	11,301	5,498	120,457
1996	80,021	25,367	11,505	5,575	122,468
1997	81,302	25,928	11,713	5,658	124,601
1998	82,602	26,500	11,926	5,743	126,771
1999	83,924	27,086	12,144	5,829	128,983
2000	85,267	27,684	12,366	5,917	131,234
2001	86,631	28,147	12,532	6,006	133,316
2002	88,191	28,617	12,701	6,107	135,616
2003	89,777	29,095	12,872	6,211	137,955
2004	91,394	29,582	13,045	6,316	140,337
2005	93,039	30,076	13,221	6,424	142,759
2006	94,341	30,617	13,396	6,508	144,863
2007	95,945	31,169	13,573	6,613	147,300
2008	97,576	31,730	13,753	6,719	149,779
2009	99,235	32,302	13,935	6,828	152,300
2010	100,922	32,884	14,120	6,938	154,863

Notes: i) The above projections of Vehicle Kilometers Travelled for Ontario are based upon information supplied, in March 1996, by the Ontario Ministry of Environment and Energy, Environmental Monitoring & Reporting Branch.

4.1.2 Ontario Hydro Commitment - December 1991

In a letter to the Minister of the Environment, dated December of 1991, the president of Ontario Hydro committed to a 40% reduction in NOx emissions from 1985 baseline levels by the year 2000. As indicated in the summary tables (see Table D.1.1 or Table D.1.2) of baseline emissions, Ontario Hydro is estimated to have emitted 95 kilotonnes of NOx emissions in 1985. 60% of the 1985 emission level (or a 40% emission reduction) represents an emission limit or cap of 58 kilotonnes of NOx. This emission limit represents a 19 kilotonne (net, including any potential growth in emissions from increasing demands for power) reduction from 1990 levels by the year 2000.

$/Tonne reduction cost estimates are based upon a review of **retrofit** costs of technologies ranging from low-NOx burners to selective catalytic reduction (reference: Multistakeholder Committee for CCME N306 Initiative: "Background Document for the Development of a National guideline for NOx Emissions from New or Modified Commercial/Industrial Boilers and Process Heaters", Working Draft #5, June/95, Table 4.6, Pg. 4-44). The most cost effective retrofit option, from this reference, is flue gas recirculation and the most expensive is Selective Catalytic Reduction:

- Flue Gas Re-Circulation (55-60% NOx control): $1426/Tonne Reduction
- Selective Catalytic Reduction (80% NOx Control): $4193/Tonne Reduction

4.1.3 INCO NOx Emission Reductions - Fuel Switching 1990-91

Up until 1990, INCO used #6 oil in its Sudbury smelting process. #6 oil contains free nitrogen and the combustion of #6 oil results in significant NOx emissions. After 1990, as a result of process changes, INCO ceased using #6 oil in the smelters. This resulted in an estimated reduction in annual NOx emissions of 43 kilotonnes. Cost information for the relevant process changes is not available.

4.1.4 Combustion Turbine Guideline - March 1994

Based upon a review of the certificates of approval issued for combustion turbines between 1972 and 1993; information, from Environment Canada, on the number of natural gas pipeline combustion turbines; uncontrolled and controlled NOx emission factors; and an assumed 80% capacity factor, NOx emission estimates for combustion turbines in 1995 are summarized as follows:

- there are estimated to be 60 combustion turbines at natural gas pipeline compressor stations in Ontario (average size is assumed to be 10 MW and average uncontrolled NOx emission factor of 600 g NOx/GJ);

- as of early 1994, there were 21 non-utility power generating combustion turbines (average size is 48 MW and median size is 42 MW);

- many of the non-utility power generating units are controlled (steam injection or Low-NOx combustor technology) with the number and average size range summarized as follows:

  - □ 11 units that are uncontrolled (850 g/GJ emission factor) with an average size range of 27 MW;

  - □ 6 units that have steam injection (60% control, assumed) with an average size range of 48 MW;

  - □ 4 units that have Low-NOx combustors (80% control, assumed) with an average size of 102 MW.

Therefore, the 1995 "baseline" NOx emissions from combustion turbines are estimated as follows:

Total NOx Emissions (combustion turbines) in 1995 =

$$\frac{60 \times (10\times10^{-3}\ \text{Gj/s})\times(3600\ \text{s/hr})\times(24\ \text{hr/day})\times(365\ \text{days/yr})\times(0.8)\times(600\ \text{g/GJ})}{10^{9}\ \text{g/Kilotonne}} +$$

$$\frac{[11\times(27\times10^{-3})\times850 + 6\times(48\times10^{-3})\times850\times0.4 + 4\times(102\times10^{-3})\times850\times0.2]\times3600\times24\times365\times0.8}{10^{9}\ \text{g/Kilotonne}} =$$

19.7 Kilotonnes (assumed to be included in "Other Industrial" category for National Emission Inventory and Projections Task Group - NEIPTG estimates)

Emission Reduction Projections due to guideline can be estimated as follows:

1995: assumed that there are no NOx emission reduction, for 1995, because of the MOEE guideline.

2000, 2005 and 2015:

- Compressor Stations: Assuming no growth in the number of compressor stations but that a combustion turbine has a useful life of 20 years (i.e, replacement rate of 5% in any given year)... then in the year 2000, it is anticipated that there will be 45 "pre-guideline" compressor station units and 15 "post-guideline" units and in 2005, 30 "pre-guideline" units and 30 "post-guideline" units. Also assume that the guideline provides 60% control for the new compressor station units.

- Non-Utility Power Generation: Assuming growth in the number non-utility power generation facilities of one per year then there will be 5 new facilities (average size of 48 MW),relative to 1995, in 2000 and 10 new facilities in

2005 and 20 new facilities by 2015. Also assume that the guideline provides 80% control for the non-utility power generating units.

- Utility Power Generation: Assuming that there will be 1, 200 MW utility combustion turbine installed between 2000 and 2005 and another one between 2005 and 2015.

Therefore, emission reduction estimates for 2000, 2005 and 2015 are summarized as follows:

2000: NOx Emission Reductions =

$$\frac{[15x(10E\text{-}03)(600x0.6) + 5x(48E\text{-}03)x(850x0.8)]x3600x24x365x0.8}{10^9} = 5.5 \text{ Kilotonnes}$$

2005: NOx Emission Reductions =

$$\frac{[30x(10E\text{-}03)(600x0.6) + (10x48E\text{-}03 + 200E\text{-}03)x(850x0.8)]x600x24x365x0.8}{10^9} =$$

14 Kilotonnes

2015: NOx Emission Reductions =

$$\frac{[60x(10E\text{-}03)(600x0.6) + (20x48E\text{-}03 + 2x200E\text{-}03)x(850x0.8)]x600x24x365x0.8}{10^9} =$$

29 Kilotonnes

Growth in NOx emissions from combustion turbines between 1990 and 2000:
(assumed to be included in projected, from NEIPTG estimates, growth for the "Other Industrial" sector)

compressor stations: assume 0
non-utility power generation: assume 5 facilities (average size of 48 MW)

therefore, increase in NOx=

$$\frac{[5x(48E\text{-}03)x(850)]x3600x24x365x0.8}{10^9} = 5.1 \text{ Kilotonnes}$$

Growth in NOx emissions from combustion turbines between 1990 and 2005:
compressor stations: assume 0
non-utility power generation: assume 10 facilities (average size of 48 MW)
utility power generation: assume 1 facility at 200 MW

therefore, increase in NOx=

$$\frac{[(10x(48E\text{-}03)+200E\text{-}03)x850]x3600x24x365x0.8}{10^9}$$

= 14 Kilotonnes

Growth in NOx emissions from combustion turbines between 1990 and 2015:

compressor stations:	assume 0
non-utility power generation:	assume 20 facilities (average size of 48 MW)
utility power generation:	assume 2 facility at (average size of 200 MW)

$$\text{therefore, increase in NOx} = \frac{[(20x(48E\text{-}03)+2x200E\text{-}03)x850]x3600x24x365x0.8}{10^9}$$

$$= \underline{\underline{29 \text{ Kilotonnes}}}$$

$/Tonne reduction cost estimates are based upon a review of cost for Low-NOx combustor technology which is fully developed for large units (i.e., over 100 MWe) and in the latter stages of development for mid-size combustion turbines (i.e., over 20 MWe) in the latter stages of development (reference: Ontario MOEE, "Emissions from Stationary Combustion Turbines in Ontario - Background Document, August 1993, Table 2-4, Pg. 13).

4.1.5 Energy Efficiency Initiatives Pre-1995

As part of the Ontario response to the climate change issue, several programs have been noted that account for energy savings. A fraction of any energy savings contributes to reduction in NO_x emissions. A list of these initiatives is listed with the associated emission reductions when known (combined NOx emission reduction estimate - included in Table G.3.1 - are estimated to be 6 kilotonnes; assumed to be 1.5 kilotonnes within the Commercial and Institutional sector and 4.5 kilotonnes within the Other Industrial sector). NOx reductions are anticipated as a "cross-linked" benefit from the reduction in fuel usage because of energy efficiency initiatives.

Utility Actions -
Ontario Hydro's Energy Efficiency Initiatives

Through 1992, Ontario Hydro estimates that its DSM programs have saved 700 megawatts (MW) in peak generation demand. Program spending and expected savings has been reduced in response to falling demand forecasts and the need to reduce operating costs. Programs have been redesigned to emphasize partnerships, education and information, and cost effectiveness. A further 700 MW of capacity savings will be achieved by 2000 for a total saving of 1400 MW.

Gas Utility Demand Management

Ontario's three major natural gas distribution utilities are formulating plans for demand management programs that will improve the efficiency of natural gas use in the Province. The Ontario Energy Board will encourage this through its integrated Resources Planning initiative. Programs include: consumer information and education; financial incentives for

high-efficiency space heating conversions; retrofit programs for insulation, high efficiency windows and water heating improvements; and technology demonstrations for industrial customers.

Government Actions

Social Housing Energy Retrofit Program (SHERP)

The SHERP program assists owners of social housing to convert their units from electrical space and water heating to other fuels, principally natural gas.

Through mid-1993 the program spent $27 million to convert 7,100 units of social housing. Long-term plans are to convert 90,000 more units by the end of the century.

Energy Efficiency Act Standards

Under the Energy Efficiency Act (1988) Ontario can establish minimum efficiency standards for 14 types of energy-using equipment sold in the province. Over 120 separate regulations have been put in place already. The major equipment covered include household refrigerators, freezers, natural gas furnaces, residential hot water heaters, industrial electric induction motors and commercial fluorescent lighting ballasts. Ontario plans to add other types of equipment to the regulated list and to progressively tighten existing standards.

Ontario Building Code (1990 and 1993) including ASHRAE 90.1

Insulation requirements in the Building Code for new housing were updated in 1990 (effective 1991) and full-height basement insulation standards were added in the 1993 Code along with even higher energy-efficiency standards for electrically-heated homes. As a result the average new gas-heated home built in 1995 will be 15 per cent more efficient than one built in 1988.

ASHRAE 90.1, an extensive set of building shell, lighting and equipment standards, was added to the Building Code as a "recommended" standard for new commercial and high-rise apartment construction.

Plumbing Code Amendments

Plumbing Code amendments will affect water flow in commercial and residential structures by establishing maximum flow rates for showerheads, toilets and faucets. Energy savings are the result of reduced demand for hot water.

Government Building Operations

Government Ministries have action plans to improve energy efficiency in government buildings by 20 per cent from 1990 levels by 2000. Despite cutbacks in government programs, the necessary retrofits are being financed through lease arrangements.

Government Fleet

The Government has targeted 20% reduction from 1990 levels in government fleet fuel use by 2000.

Rapid Transit Expansion

Ontario has announced detailed plans to substantially expand the public transit network over the decade.

Fuel Taxes

To promote greater fuel conservation, the 1991 Ontario Budget raised taxes on gasoline and diesel fuel. Taxes on both fuels increased by 3.4 cents per litre in two stages.

Tax for Fuel Conservation

The tax for fuel conservation imposes taxes of $75 to $7,000 on less fuel efficient vehicles and offers a $100 rebate for the most fuel efficient vehicles (less than 6.0 litres per 100 km driven). This tax is designed to affect consumers' decisions at the point of sale, rewarding conservation action and stimulating purchases of more fuel efficient autos. Between 1990 and 1992, the sales of the most fuel-efficient cars tripled to 24,000, while those of the least efficient fell from 21,200 to 7,700.

Alternative Transportation Fuels (ATFs)

The Province encourages the substitution of fuels such as propane, natural gas and alcohol-based fuels for motor gasoline and diesel fuel. Sales tax rebates for conversions and equipment and lower (propane) or no fuel taxes are major financial incentives. Propane is already well established for taxis and delivery fleets while NGV use is growing in fleets and as a substitute for diesel in transit buses. Alcohol blends are sold at a number of filling stations throughout the Province and commercial distillers are planning substantial increases in fuel alcohol production capacity in the next few years.

Market Action

Fuel Substitution for Electricity

Many Ontario households are converting their heating systems from electricity to natural gas. From 1993 to 2000 an estimated 58,000 private housing units of all types are expected to convert space and water heating from electricity to natural gas. (Need separate figures for spare and water heat).

4.1.6 Canadian Chemical Producers Association (NERM) Initiatives

In late 1993, the Canadian Chemical Producers Association launched, as part of Responsible Care, a "Reducing Emissions" National Emissions Release Monitoring Initiative. The program provided a 1992 emission inventory and five year emission reduction projections. They also reported that they would reduce NOx and VOC emissions by 22% (1992 baseline of 11 kilotonnes) and 15% (1992 baseline of 20 kilotonnes) respectively by 1997. In the 1994 report, the CCPA reported the total NOx emissions were 20% less than they were in 1993 and VOC emissions were 6% less than they were in 1993. The major portion of this decline was due to the reduction progress made by five facilities which used a number of techniques including: VOC emission reduction through collection and use as fuel; heat exchanger modifications to reduce VOC emissions; fugitive VOC emission reduction from valves, fittings and pump seals through leak detection and preventative maintenance programs; and VOC reductions through the use of new cleaner production technology.

4.2 Notes for Existing and Committed VOC Emission Reductions/Costs

4.2.1 Vehicle Emission Standards - 1988 and 1994-96

An MOU between the Automobile Manufacturers and Transport Canada resulted in an introduction of Tier 1 vehicles on a schedule similar to that of the USA. The standards will be phased in over a three year period: 40% for the 1994 model year, 80% in 1995 and 100% in 1996 model year. Transport Canada has not yet amended the required regulation but is planning to do so. The MOU required new vehicles to meet a standard of 0.4 g/mi for NO_X, 0.25 g/mi for VOC, and 3.4 g/mi for CO.

The CCME Management Plan for NO_X and VOCs suggested a reduction in Reid Vapour Pressure (RVP - volatility) of gasoline to 9 psi. Ontario has passed a regulation controlling RVP at 10.5 psi for the summer months. Ontario has controlled summer gasoline volatility since 1989. In 1989 and 1990, seasonal regulation required a cap of 10.5 psi for the summer volatility of gasoline. In 1991, a permanent regulation, Ontario Regulation 271/91 was enacted. Environment Canada has estimated that 10.5 psi would yield a 12 kt reduction in VOCs (this has been included in the 2015 projections - included in the third column of Table G.3.2).

4.2.2 Consumer Products (V103)

In Phase I of the CCME Management Plan for NO_x and VOCs an initiative to reduce VOC emissions from consumer products by 20% from 1985 levels by 1997 was identified as V103. The consumer products considered excluded windshield washer fluid, coatings, adhesives and sealants. The initiative was to build on the similar program under development by the US EPA. The US study results were not published until 1996 and thus the initiative is behind schedule.

Industry representatives informed the task force assigned to report on this initiative that the goal was reasonable. they wanted assurance that compatibility with US national programs would be maintained. Suitable inventory data were available, however, there are some problems in determining the portion entering the atmosphere.

Although the problem with the portion of these products evaporating to the atmosphere is not resolved, emissions from this sector are probably about 80 kt. The anticipated 20% reduction would give an emission reduction of 16 kt. However, the existing committed reductions are estimated to be approximately 7 kilotonnes.

4.2.3 Cleaning/Degreasing (V309/V614)

Solvent cleaning/degreasing involves the use of organic solvents, in either the liquid or vapour phase, to remove soils such as cutting oils, metal particles, soldering fluxes and waxes from fabricated articles. Degreasing is generally carried out prior to final use, as in the case of printed wiring boards, or prior to subsequent treatment, such as metal finishing or painting.

Organic solvent cleaning/degreasing does not constitute a distinct industrial category, and solvent degreasers are an integral part of many industrial sectors. The estimated VOC emissions from solvent cleaning/degreasing were in excess of 17 kilotonnes in 1985. Without controls, these were expected to increase to 19 kilotonnes by 2005.

The CCME NOX/VOC initiative conducted studies in this sector from 1992 to 1994 and developed a code of practice for the control of VOC emissions in 1994. The code set out 58 specific initiatives to reduce NOx and VOC emissions from existing and new sources. The code is in four parts:

application and scope;

- design, equipment, performance and operating standards for new solvent degreasers and for retro-fitting existing degreasing facilities;

- record-keeping and test methods that will assist owners and authorities in measuring compliance and operating efficiencies; and

- an operator training program.

The code follows the general trend in the industry sector of switching to aqueous and semi-aqueous cleaners for solvent vapour degreasers in simple fabrication and finishing operations. Both immersion and spray methods are employed. Low vapour pressure hydrocarbons, glycol ethers, ketones, and blends of these solvents are also being used as substitutes for ozone depleting compounds and hazardous air pollutants in the following applications: removal of high-viscosity metalworking fluids and straight oils; removal of preservative oils; cleaning during equipment maintenance and service; and wipe cleaning during assembly. To enhance the effectiveness of aqueous and semi-aqueous cleaners, various methods of mechanical agitation, the use of ultrasonics, and the substitution of emulsifiable metalworking fluids have been implemented. The industry is also examining the entire manufacturing system in an attempt to identify methods to reduce or eliminate the need for cleaning and degreasing, while concurrently attempting to optimize the substitute materials and processes. The CCME study estimated that an 80% reduction in emissions can be achieved for new degreasing facilities (built after 1995), and an average 50% reduction in emissions for the year 2005 was possible for existing facilities.

4.2.4 Adhesives/Sealants (V102)

The Adhesives and Sealants Manufacturing Association of Canada (ASMAC) presented statistics to the multistakeholder task force on adhesives and sealants. The presentation noted anticipation of a 40% reduction in VOCs by 1997. It showed that solvent use by association had dropped from 7.2 kt to 5.4 kt or a 25% reduction between 1985 and 1992.

The task force recommended that no further action be taken on this initiative, other than to continue to monitor ASMAC data on an annual basis.

4.2.5 Consumer Surface Coating (V101)

Consumer surface coating applications are a major source of VOC emissions in Ontario - 122 kt. The paint and coating industry consists of manufacturers of paints, varnishes, and stains. There have been changes occurring in the industry. For instance, the ratio of waterborne to solvent borne paints has increased from 45% in 1985 to 60% in 1992. The performance of waterborne coatings has improved and the clean-up with soap and water and rapid drying properties make them convenient to use. A higher sensitivity to environmental issues among institutional specifiers has contributed to increased use of waterbornes.

Consumer coating applications include three main sectors, residential, industrial, and industrial/commercial architectural. Anticipated VOC reductions in from these sectors are residential 4 kt, industrial 9 kt, and industrial/commercial architectural 9 kt. It is anticipated that 17 and 5 kilotonnes of these reductions are defined as "existing committed" and "future readily available opportunities", respectively.

The consumer products industry should achieve a 20% or 27 kt reduction in VOCs by 1997. A further 15-30% reduction should be available over the next ten years.

Recommendations of the task force were:

#1 A memorandum of understanding between the coating industry and the National Air Issues Coordinating Committee (NAICC) should be developed.

#2 The NAICC should commit itself to clarify and harmonize the various inventories undertaken by several government bodies and to strengthen their data bases.

#3 The Environmental Choice Program requirements should be included in Canadian General Standards Board (CGSB) standards, and CGSB should be asked to revise their coatings specifications and make them performance standards rather than composition specifications.

4.2.6 Industrial/Commercial Initiatives (Surface Coating Facilities - V307/V612)

The surface coating facilities sector consists of manufacturing activities which apply coatings to their products including: automobile manufacturing; auto parts; auto refinish; wood products; appliances; coil coating; general metal finishing; and other metal products manufacturing areas. The total VOC emissions from this sector is expected to decline by 6% by the year 2000. This projection takes into account business conditions, plant closures, as well as changes in coating or application technology that have been adopted and are expected to continue to impact the industry. The expected VOC reduction and control options include:

- improved operations management; better solvent handling and capture for recycling and disposal; reduction in coatings and solvent consumption;
- adoption of techniques and/or equipment to improve coating transfer efficiencies;
- adoption of coatings with increased solids and lower VOC content (even water-borne coatings); and
- installation of control devices to collect, destroy and/or recycle potential VOC emissions.

The current expected costs for controlling the emissions from this sector range from about $850 million ($38,000 per tonne of VOC removed) for a 35% reduction to $3,000 million ($57,000 per tonne of VOC removal) for a 78% reduction.

The CCME NOx/VOC program initiated in 1993, a number of activities to develop codes of practice and controls for this sector. To date two subsectors, automobile manufacturers and automobile refinishers, have been completed.

The automobile manufacturing subsector includes coating facilities in automotive assembly plants for automobiles, passenger vans, sport/utility vehicles and light duty trucks. The

automotive coating facilities are used for the application of individual layers of various types of coatings to body shells. The coatings are organic in nature and are applied for protective and aesthetic purposes or both. The VOC emissions from this sector were 28 kilotonnes/year in 1985 and 16 kilotonnes/year in 1993. The CCME initiative developed and approved a code of practice and performance standards for this subsector in 1995. The performance standards require the automotive facilities to reduce their emissions to: 55 grams of VOC for cars, 60 grams of VOC for passenger vans, and 75 grams of VOC for light duty trucks by per square meter of surface covered by 2005. The standard is expected to reduce the VOC emissions by a further 4 kilotonnes (with a total reduction of 57% since 1985).

The automobile refinishing subsector deals with the repair and refinishing of automobiles, light duty trucks and vans. It is comprised of a large number of facilities which are distributed across Ontario in approximate agreement with the distribution of population. Automotive refinish facilities range from very small, one man operations to ones having 25 or more employees. The emissions from this subsector average about 6 kilotonnes per year. The CCME initiative developed a code of practice and VOC content standards for paint for this subsector in 1995. The VOC content standard for paint will result in a 30% reduction in VOC emissions, while the code of practice which mandates the use of high efficiency application equipment and a solvent management system will provide a 25% reduction in VOC emissions. These requirements are expected to be in-place by 2000.

Activities will be initiated shortly in the wood products and auto parts subsectors. VOC reduction results which are similar to the automotive refinisher subsector are expected.

4.2.7 Vapour Recovery at Gas Distribution Centers (Stage I)

Fuel evaporation on gasoline distribution is a source of VOCs in the Southern Ontario Corridor. A regulation requiring installation of vapour recovery systems during gasoline distribution was promulgated in 1994. By 1998, all service stations and fuel terminals in Southern Ontario will be required to have a vapour recovery system in place. The estimated VOC emission reductions will be 19 kt.

4.2.8 Can. Chemical Producers Association (NERM) Initiatives

Similar to the information in section 4.1.6, in late 1993, the Canadian Chemical Producers Association launched, as part of Responsible Care, a "Reducing Emissions" National Emissions Release Monitoring Initiative. The program provided a 1992 emission inventory and five year emission reduction projections. They also reported that they would reduce VOC emissions by 15% (1992 baseline of 20 kilotonnes) by 1997. In the 1994 report, the CCPA reported that VOC emissions were 6% less than they were in 1993. The major portion of this decline was due to the reduction progress made by five facilities which used a number of techniques including: VOC emission reduction through collection and use as fuel; heat exchanger modifications to reduce VOC emissions; fugitive VOC emission reduction from

valves, fittings and pump seals through leak detection and preventative maintenance programs; and VOC reductions through the use of new cleaner production technology.

4.2.9 Dry Cleaning Initiative

A regulation requiring dry cleaners to have a full time staff member that had taken an environmental training course on the proper handling of dry cleaning solvents by June 1996. It is anticipated that the measures taught in the course would yield sufficient economic benefits that the dry cleaners would implement the changes voluntarily. The reduction in VOC emissions should be about 0.9 kt.

5.0 "READILY AVAILABLE" OPPORTUNITIES for EMISSION REDUCTIONS

5.1 Notes for "Readily Available" NOx Emission Reductions/Costs

This section describes the readily available opportunities for emission reductions.

5.1.1 Updated Light Duty Vehicle Emission Standards - "49 State" Low Emission Vehicle Standards

A draft MOEE document titled, "Projected Emissions from Light Duty Gasoline Vehicles, February 1996", provides estimates of NOx and VOC emission reductions between the years 1995 and 2020 (at five year increments) for a variety of emission standard and inspection and maintenance scenarios. For the purposes of this report the following emission reduction scenario was considered:

Measure	Short-Term Reduction Period
FED-LEV Program or "49 State" Low Emission Vehicle Standard	post 1995 to 2005

Notes:
i) Emission reductions, between the years 1995 and 2005, for VOCs and NOx were obtained from separating the combined emission reductions (i.e., combination of new standards plus I&M programs) from information contained in appendices B and C, respectively, from the above noted reference document.
ii) Growth rates are incorporated into the stated emission reduction estimates.

5.1.2 Inspection and Maintenance Program

The above noted draft MOEE document was also used to provide estimates of NOx and VOC emission reductions between the years 1995 and 2005 for a mandatory inspection and maintenance program scenario. For the purposes of this report the following emission reduction scenario was considered:

Measure	Short-Term Reduction Period
Mandatory IM240 Inspection & Maintenance Program	post 1995 to 2005

Notes:
i) Emission reductions, between the years 1995 and 2005, for VOCs and NOx were obtained from separating the combined emission reductions (i.e., combination of new standards plus I&M programs) from information contained in appendices B and C, respectively, from the above noted reference document.
ii) The IM240 program is similar to the existing voluntary I&M program in Ontario. The above scenario assumes that the program is made mandatory with an annual inspection requirement.
iii) Growth rates are incorporated into the stated emission reduction estimates.

Ontario currently has a pilot voluntary program operating and is investigating potential implementation options for a further program (see note i under Table G.3.3).

5.1.3 Voluntary Emission Reduction Targets for Large Industrial Facilities

It is assumed that "larger facilities" will mean iron & steel production, oil refining and cement facilities in southern Ontario. It is also assumed that reduction targets for 2005 and 2015 will be in the range of 25% and 35%, respectively. However, it is anticipated that the Voluntary Emission Reduction will allow for reductions of either NOx or VOCs and the Oil Refining and Cement sectors may reduce VOCs more readily than NOx. Therefore, for the oil refining sector assumed NOx emission reductions will be 15 and 25%, respectively.

5.1.3 Voluntary Emission Reduction Targets for Large Industrial Facilities continued

Baseline 1990 - NOx Emission Estimates (from NEIPTG Consensus National Base Case Forecast, March 1996):

Iron & Steel:	22 kilotonnes in 1990
Oil Refining:	14 Kilotonnes in 1990
Cement:	10 Kilotonnes in 1990

Emission Reduction Forecasts - Based Upon Voluntary Emission Reduction Targets are as follows:

2005: NOx Emission Reductions = (22x0.25) + (14x0.15) + (10x0.25) = 10 Kilotonnes

2015: NOx Emission Reductions = (22x0.35) + (14x0.25) + (10x0.25) = 14 Kilotonnes

Cost estimates are from "Draft Background Document for the Development of a National Guideline for NOx Emissions from New or Modified Commercial/Industrial Boilers and Process Heaters, Prepared by Working Group #1 for the Multistakeholder Steering Committee for Initiative N306. The estimates are based on the following assumptions:

- Iron & Steel and Oil Refining: low-NOx burners or energy efficiency or process changes;
- Cement manufacture: use of selective catalytic reduction; energy efficiency or process changes.

5.1.4 Guideline for New, Large Boilers

As a result of the CCME N306 effort, the MOEE could implement new source performance guidelines as conditions on Certificates of Approval for large boilers (i.e., over 100 to 200

MM Btu/hr capacity). Assumptions for these NOx emission reduction estimates for this effort are summarized as follows:

- Assume 50% of total stationary NOx emissions are from boilers;
- Assume 30% of capacity are large boilers;
- Assume 5% replacement rate;
- Assume 50% of large boilers not already affected by Voluntary Emission Reduction Targets for Large Facilities;
- NSPG provides for a 50% reduction;
- Assume 25% actually achieve reductions; and
- Baseline-1995 NOx emissions for stationary (non-utility) sources is 145 Kilotonnes.

Therefore, NOx emission reduction estimates for 2005 and 2015 are as follows:

2005: 0.5x0.3(0.05x10)x0.5x0.5x0.25x145 = 0.7 Kilotonnes

2015: 0.5x0.3(0.05x20)x0.5x0.5x0.25x145 = 1.4 Kilotonnes

Cost estimates for the guideline for New, Larger boilers are based upon the use of low-NOx burners or flue gas re-circulation. Costs include capital, installation and operating costs and are derived from "Draft Background Document for the Development of a National Guideline for NOx Emissions from New or Modified Commercial/Industrial Boilers and Process Heaters.

5.1.5 Design or Performance Standards for New Boilers

It is anticipated that a Canadian standards council organization will cooperate with Environment Canada, the MOEE and a number of industrial associations to develop a new performance based standard (i.e., implemented and certified by the CSA or similar). Assumptions for these NOx emission reduction estimates are as follows:

- Assume 50% of total stationary NOx emissions are from boilers;
- Assume the new standard is applicable to 25% of the boiler population (by capacity);
- Assume a 5% replacement rate;
- Assume 25% NOx emission reduction from new standard; and
- Assume 25% actually achieve reduction.

Therefore, NOx emission reduction estimates for 2005 and 2015 are as follows:

2005: 0.5x0.25(0.05x10)x0.25x0.25x145 = 0.6 Kilotonnes

2015: 0.5x0.25(0.05x20)x0.25x0.25x145 = 1.1 Kilotonnes

Cost estimates for the design or performance standards are based upon the use of low-NOx burners or flue gas re-circulation. Costs include capital, installation and operating costs and are derived from "Draft Background Document for the Development of a National Guideline for NOx Emissions from New or Modified Commercial/Industrial Boilers and Process Heaters.

5.1.6 Voluntary Boiler Inspection and Maintenance

It is anticipated that the Ontario Natural Gas Association and the Canadian Boiler Society will cooperate with the MOEE to implement a voluntary boiler inspection and maintenance program that will be "driven" by energy savings to the users of boilers. NOx emission reductions will be a by-product of this effort and can be estimated based upon the following assumptions:

- assume, a 5% average energy efficiency and NOx emission reduction improvement from the boiler inspection and maintenance within, primarily, the commercial and institutional sector;
- 25% participation rate by the year 2005;
- 40% participation rate by the year 2015; and
- baseline-1995 NOx emissions from the commercial and institutional sector of 10 Kilotonnes (from NEIPTG, March 1996).

Therefore, NOx emission reduction estimates for 2005 and 2015 are as follows:

2005: 0.05x0.25x10 = 0.1 Kilotonnes

2015: 0.05x0.4x10 = 0.2 Kilotonnes

It is anticipated that this voluntary program will be driven by energy-savings and any costs will have a reasonable pay-back period.

5.2 Notes for "Readily Available" VOC Emission Reductions/Costs

5.2.1 Updated Light Duty Vehicle Emission Standards - "49 State" Low Emission Vehicle Standards

The 1995 CCME Deputy Minister's Task Force on Cleaner Vehicles and Fuels recommended the introduction of low emission vehicles (LEV) in concert with the USA. If agreement is reached in the US between the Northeastern States and the automobile manufacturers LEVs could start being introduced as early as 1998 but will be required by 2001. LEV have emission rates below 0.2 g/mi for NO_X, 0.075 g/mi for VOCs, and 1.7 g/mi for CO. Vehicle emission reductions from this initiative are anticipated to be 4 and 3 kt of NO_X and VOCs, respectively.

The CCME Task Force also recommended initiatives on improving vehicle fuel efficiency and removing market impediments to alternate fuels and technology. Environment Canada and Industry Canada are developing initiatives in these areas.

5.2.2 Fuel - Reid Vapour Pressure - Future

The CCME Task Force recommended that The Reid Vapour Pressure (RVP or gasoline volatility) in the Windsor-Quebec Corridor be reduced to 9.0 psi during summer months starting in the summer of 1996. CPPI have agreed to the reduction in volatility but have stated that full implementation is not possible until the summer of 1997. The RVP is the only fuel component requiring provincial action.

All other fuel components under discussion by the CCME Task Force were to be acted upon by the federal government.

Environment Canada has drafted legislation to require low sulphur diesel for all on-road use; CPPI has agreed to this action.

Environment Canada has also drafted legislation controlling benzene, sulphur content of gasoline and toxic emissions from gasoline use. CPPI agrees with the reduction in benzene but is concerned about the level specified which it feels should be harmonized with the US approach. CPPI also objects to any decisions being made on sulphur in gasoline because it doesn't feel their is sufficient data to act and also believes that Environment Canada should wait for the outcome of US studies. CPPI further takes issue with Environment Canada's suggested model for assessing levels of Toxic emissions and believes that only benzene should be considered at this time.

5.2.3 Inspection and Maintenance Program

Recommended Provincial initiatives included vehicle emission inspection and maintenance (I&M) programs and scrappage of old vehicles in poor repair. Ontario currently has a pilot voluntary program operating and is investigating potential implementation options for a further program (see note ii under Table G.3.4).

5.2.4 Printing Sector Initiatives

The distribution of printing establishments follows commercial and manufacturing activity Canada. Most of the printers are located in Ontario and Quebec and are concentrated within the metropolitan areas. VOCs come into printing plants in the form of purchased solvents, formulated cleaning compounds or contained in ink and fountain damping solution formulations. For the industry as a whole, approximately 77% of VOCs entering the plants and used in the printing process are emitted to the atmosphere. The remainder is captured and destroyed, or transferred outside of the plant boundary for disposal or recycling by a third party. The 1993 Ontario VOC emissions were approximately 30 kilotonnes per year

with about 20 kilotonnes arising from printing on plastics, 2 kilotonnes from printing on folding cartons, 2 kilotonnes from large custom printers, 2 kilotonnes from printing on wallpaper and remaining 12 printing categories providing the rest. When emissions are subdivided by printing technology, flexographic printing accounts for 62% of the VOC emissions, gravure 16%, lithographic 15%, screen printing 2%, letterpress 1% and others 4%.

In 1993, the CCME NOX/VOC program initiated the development of a VOC reduction program for the printing industry. A proposed code of practice and new performance standards were developed in 1995 for flexographic printing technologies. Flexographic printing is used for a variety of products including plastic films for packaging, folding and corrugated paper cartons, newspapers and labels. The intent of the proposed code and performance standards is to recommend feasible VOC reduction and control options that:

- minimize VOC emissions from new installations through the application of add-on controls, or suitable alternate technologies;
- encourage the installation of presses that use low VOC content inks; and
- minimize VOC emissions from equipment cleaners.

The VOC add-on controls include thermal and catalytic incineration and carbon adsorption and range from $300 for large facilities to $4,000 for small facilities per tonne of VOC removed per year. An attractive option for small flexographic presses for some applications is the use of low VOC ink technology. These technologies include ultraviolet cured inks and water-based inks. Adoption of water-based ink technology provides a level of control comparable to that achieved by add-on controls. The aim of the code and new performance standards is to achieve a 60 to 90% VOC emissions reduction for major VOC sources. The draft code and performance standards are being reviewed by industry and Environment Canada and finalization is expected in 1997.

A proposed code of practice and new performance standards for lithographic printing were developed in 1994. The proposed new standards were intended to reduce emissions from the three lithographic printing technologies as follows:

heatset web:	emissions reduction through the application of control technologies;
non-heatset web:	emissions reduction through the application of control technologies if isopropyl alcohol and solvent cleaner reductions are not possible; and
sheetfed:	emissions reduction through the application of control technologies if isopropyl alcohol and solvent cleaner reductions are not possible.

The aim of the code and new performance standards is to achieve a 70 to 90% VOC emissions reduction for major VOC sources. The draft code and performance standards are being reviewed by industry and Environment Canada and finalization is expected in 1996.

5.2.5 Ind/Comm Initiatives (V307/V612) - Future

The 10 kilotonnes of VOC emission reductions listed in Table G.2.4 under Ind/Comm Initiatives (V307/V612) are based on future projections of activities (as a result of CCME guidelines and/or codes of practice) in the automotive, wood products, packaging, metal finishing and fabric coating sectors.

5.2.6 Consumer Surface Coating (V101) Future

Consumer coating applications include three main sectors, residential, industrial, and industrial/commercial architectural. Anticipated VOC reductions from these sectors are residential 4 kt, industrial 9 kt, and industrial/commercial architectural 9 kt. It is anticipated that 17 and 5 kilotonnes of these reductions are defined as "existing committed" and "future readily available opportunities", respectively.

5.2.7 Petroleum Refinery Fugitives

As part of the CCME Management Plan for NOx and VOCs, initiatives were identified to reduce VOC emissions from storage tanks, chemical stacks, valves and plastics processes. Codes of practice were developed for each area, the codes assumed a command and control approach. The storage tank initiative required a floating roof with a secondary seal on volatile liquid storage tanks greater than 4 m diameter, if the liquid has a vapour pressure greater than 76 kph. The stack emission code of practice requires incineration of the stack emissions if the emissions are above 20 ppm or if the VOC recovery process used is not sufficiently effective. For fugitive emissions from valves and fittings, different leak detection and repair intervals are specified depending on the per cent of leaking valves found. The command and control approach to implementation of these initiatives does not fit with the Ontario situation. The Ontario approach has been to allow industry time to adopt these programs on a voluntary basis and to develop memoranda of understanding with sectors, the codes are available to the industries, but they need only choose those that give the most cost effective emission reductions. These MOUs concentrate heavily on VOC emission reductions. There are economic incentives to reduce these fugitives and industry is in the process of reducing emissions to get a better return on its investment. If these voluntary approaches fail, other means of implementation will need to be developed.

6.0 EMISSION REDUCTION SCENARIOS

6.1 Reductions Needed Beyond Existing and Readily Available Reductions for NO_X

The emission reductions (with growth) required to meet the 45% reduction goal is calculated as follows. The emission rate for 1990, 659 kt for NO_X, was multiplied by 55% to obtain the target emission level of 362 kt. The baseline emission rate for 2015, 933 kt for NO_X from Table G.2.2, was reduced by the existing and readily available emission reductions, 257 kt for NO_X, to give an anticipated emission level of 676 kt. The required reductions are thus 676 kt - 362 kt = 314 kt.

6.2 Reductions Needed Beyond Existing and Readily Available Reductions for VOCs

The emission reductions (with growth) required to meet the 45% reduction goal is calculated as follows. The emission rate for 1990, 868 kt for VOCs was multiplied by 55% to obtain the target emission level of 477 kt. The baseline emission rate for 2015, 1215 kt for VOCs from Table G.2.2, was reduced by the existing and readily available emission reductions, 260 kt for VOCs, to give an anticipated emission level of 955 kt. The required reductions are thus 955 kt - 477 kt = 478 kt.

6.3 Reductions Relative to Unreduced Emissions (Scenarios 1 and 2)

Two emission reduction scenarios were examined in "Towards a Smog Plan in Ontario". These scenarios were identified as:

1. EXISTING AND READILY AVAILABLE REDUCTIONS, relative to a base case of unreduced emissions in the year 2015.

2. 45% REDUCTION OF 1990 NO_x AND VOC EMISSIONS, relative to a base case of unreduced emissions in the year 2015.

Scenario 1 reductions are the amount obtained through existing and readily available reductions, as summarized in Table A of the Appendix in "Towards a Smog Plan for Ontario". Scenario 2 reductions are the amount obtained by subtracting 55% of the 1990 baseline emissions (Table G.2.2) from the 2015 baseline emissions (also in Table G.2.2). The values of these reductions are summarized in Table G.6.1.

Table G.6.1 Emission Reductions Relative to 2015 Unreduced Emissions for Two Scenarios

Scenarios	NO_x Reductions (kt)	VOC Reductions (kt)
EXISTING AND READILY AVAILABLE REDUCTIONS, relative to a base case of unreduced emissions in the year 2015.	257	260
45% REDUCTION OF 1990 NO_x AND VOC EMISSIONS, relative to a base case of unreduced emissions in the year 2015.	571	738

References

1) Canadian Council of Ministers of the Environment (CCME), "Background Document for the Development of a National Guideline for NOx Emissions from New or Modified Commercial/Industrial Boilers and Process Heaters", prepared by Working Group #1 for the Multistakeholder Steering Committee for Initiative N306, Working Draft #5, June 1995.

2) National Emissions Inventory and Projections Task Group (NEIPTG), "Consensus National Base Case Forecast - version 2.1", March 1996.

3) Ontario Ministry of Environment and Energy, "Guideline for Emission Limits for Combustion Turbines", March 1994.

4) Ontario Ministry of Environment and Energy, Env. Monitoring & Reporting Branch, "Fast Reference Emission Document (Draft) - version 3", January 1996.

SECTION H

BENEFITS-COST ANALYSES OF INHALABLE PARTICULATES AND OZONE OBJECTIVES IN ONTARIO

SECTION H

BENEFIT-COST ANALYSES OF INHALABLE PARTICULATES AND OZONE OBJECTIVES IN ONTARIO

1 Additional Tools are Needed to Evaluate and Develop Environmental Goals and Objectives

Governments apply a wide variety of statutes, regulations, judicial precedents, guidelines, administrative procedures, standards and policy statements to develop environmental protection strategies. Some strategy options are intended to **reduce or eliminate** existing pollution problems such as emissions of smog precursors. Other strategies are designed to **prevent** future adverse environmental damages.

Key elements that make up an environmental protection strategy include **setting standards or objectives** (i.e., ambient quality standards, discharge limits), **monitoring**, **pollution abatement or prevention "technologies"** (including reducing output or changing processes) and **implementation incentives** to induce emissions sources to comply with standards and objectives or to take voluntary actions.

In most jurisdictions, environmental standards and objectives are developed with one of two approaches. One approach seeks to establish ambient quality exposure standards or thresholds below which there are no known adverse effects. The second standard setting approach involves the determination of maximum allowable discharges or emissions release limits that could be achieved by the application of "best available pollution abatement or prevention technologies".

Both of these traditional methods for setting objectives have critical limitations. With regard to ambient exposure thresholds, research has revealed that, for many contaminants, no-effects thresholds do not exist. Varying degrees of adverse human health and other effects are realized at any ambient exposure level above zero. However, the lower the ambient contaminant levels are achieved, the smaller the magnitude of incremental benefits are realized and the greater the uncertainty that is associated with these benefits.

Concerning the development of pollution release limits, pollution prevention and abatement technologies are not static and change over time. "Best" technologies today in terms of removal efficiency may be displaced by new technologies in only a few years. Moreover, pollution release standards that are based on "best available technologies" may not be sufficient to prevent damages to the environment or to people.

Neither approach to standard setting takes explicit account of the costs of compliance that are imposed on pollution sources. Where sources have already made investments to reduce pollution loadings, incremental costs of installing the latest "best available technologies" to achieve further

reductions can rise substantially. High compliance costs provoke complaints and resistance to implementation of objectives by pollution sources.

The "best available technology" approach is sometimes combined with the "Economically Achievable" principle, which involves consideration of the financial effects of compliance costs on regulated parties. However, this approach is limited as a decision-making tool because it focuses on the financial effects of costs on pollution sources and does not incorporate the environmental effects and damages that are associated with given levels of discharge.

Finally, neither type of standard setting approach ultimately provides any incentive for regulated parties to develop or adopt new processes or technologies that achieve greater degrees of pollution reduction.

Given these limitations and the growing scarcity of public and private resources for environmental protection, additional methods are needed to help set ambient quality or pollution release standards and to evaluate policy and program options. A benefit-cost evaluation framework has been developed for application to environmental issues by the Ontario Ministry of the Environment and Energy.

Modifications and enhancements that make the framework more useful for environmental issues are described in the next section. Methods intended to quantify and value public benefits of environmental protection are discussed in section 2 below. This is followed by presentation of empirical estimates of the values of benefits of the two key scenarios or goals that have been specified in the discussion paper entitled "Towards a Smog Plan for Ontario".

2 A Modified Benefit-Cost Analysis Framework For Environmental Issues

Benefit-cost analysis is an analytical tool that has been used for many decades to evaluate public-sector investments, especially large water resource projects in North America. Economists have advanced the theoretical rigor of the technique over the past 20 years and have extended its application to a wide range of public policy questions, including environmental protection (Halvarsen and Ruby, 1981; Hufschmidt et al., 1983; Desvousges and Smith, April 1983; Kneese and Schulze, 1985; Donnan, January 1986; Smith, 1988).

The primary intent of a benefit-cost analysis is to ensure that public funds and resources are directed to investments and activities whose value of benefits exceed, or at least equal, their costs. In addition, benefit-cost analyses have been applied to rank potential projects according to their net benefit, to compare and choose among policies or programs that achieve different types of objectives or to determine how much funding to devote to a given project (Krupnick, 1992). Benefit-cost analyses are applied to evaluate the economic efficiency of a project or a program by ascertaining whether the value of all benefits to "gainers" are greater than the value of all costs and losses to "losers". If the value of costs is greater than the value of all quantified benefits, the economic rationale for the project or program would be questioned.

Many jurisdictions are convinced that the application of benefit-cost analyses can improve decision-making. The State of New York has embraced the technique as the primary method for evaluating regulatory policies and programs that impose large costs on regulated parties or the government (New York State, Governors's Office of Regulatory Reform, January 1996). The U. S. EPA also applies benefit-cost assessments to various regulatory issues as permitted by law.

Critics argue that the application of benefit-cost analysis to environmental issues not only does not produce results that are convincing to decision-makers, it has become a focus of conflict and debate. Adams (1996) contends that benefit-cost analysis increases the scale of environmental controversies because monetary values of intangible environmental attributes cannot be reliably estimated; where they are generated, monetary value estimates are systematically underestimated, and its application entrenches rather than resolves conflict.

Moreover, economists who have applied benefit-cost analyses to environmental and workplace health and safety policy issues have identified operational limitations with the aim of suggesting modifications to overcome these and other alleged weaknesses.

1) Many beneficial consequences of environmental protection are not bought and sold in markets and do not have market prices associated with them with which to easily value the benefits of policies and programs.

2) Some environmental effects and consequences take many years to manifest themselves. Consequently, environmental and health damages or the benefits of preventing and curtailing pollution will not be realized for years in the future. The values of these future damages (or benefits) are discounted to make them comparable with cost incurred in the present. When discounting to calculate present values is applied in benefit-cost assessments, it substantially reduces the magnitude (and importance) of these future benefits or costs.

3) Where damages of inaction or the benefits environmental protection investments now span generations, concerns about sustainability arise. Where policies or programs may be judged efficient by a benefit-cost analysis, they may not be sustainable if the economic opportunities associated with each generation's resource endowments are not at least as large as the opportunities available to earlier generations. (Woodward and Bishop, 1995)

4) Focusing only on monetary values of damages or benefits hides important information and social issues that empirical estimates of the various bio-physical effects can reveal.

5) Dose-response relationships that relate contaminant exposures to specific ecological and human health effects or that correlate remediation activities with beneficial consequences are often uncertain. Prediction of ecological effects and their implications for people require interdisciplinary collaborations.

6) Distribution of benefits and costs are important. Aggregating the value of benefits and costs hides distribution information. Debates can arise because "winners" do not usually compensate "losers" after implementing specific programs or policies.

Despite these criticisms and possible weaknesses, benefit-cost analyses can be helpful to public policy development and decision-making for the following reasons.

1) Benefit-cost analysis explicitly links environmental protection actions with environmental outcomes and economic implications,

2) The technique can be used to evaluate objectives established by the traditional approaches (ie. "no-effects thresholds" or " best-available technology"),

3) Results can indicate slight adjustments (more or less stringent) to be made in objectives or policies or provide information that can support such standards.

4) Benefit-cost analysis provides a framework for integrating relevant biophysical and economic data so that costs, benefits and other consequences of a program or project are made explicit and presented in a clear, comparable manner for stakeholder review.

5) Implications for trade-offs among different levels of costs and resulting consequences are made explicit.

6) Completing a detailed benefit-cost analysis often forces analysts to search out and evaluate a wider range of options and technologies that achieve desired benefits or objectives than would otherwise have been considered.

The results of a benefit-cost analysis alone should not dictate policy choices. Other considerations are important in the development of environmental policies and decisions regarding their implementation including legal responsibility and the possibility of "regulatory negligence".

The following modifications and analytical techniques are recommended to better accommodate environmental issues (Donnan, January 1986).

1) Quantitative human health and ecological risk assessments should be a part of all major benefit-cost analyses .

2) Quantitative estimates of benefits are displayed separately from monetary value estimates in order to give readers a full appreciation of the nature of the beneficial consequences of remediation and prevention.

3) Perceived, aesthetic effects associated with contaminated sites and their remediation are explicitly recognized and procedures to quantify and value them are suggested.

4) Relevant damages and benefits are quantified in terms of applicable biophysical units (eg. reduced heath effects, fish-kills avoided, etc.) prior to estimation of associated monetary values.

5) Uncertainties in quantitative estimates of benefits and costs are explicitly acknowledged. Where data are available, results should be presented as probabilities or as a contingency analysis.

6) Estimates of future monetary values of benefits and costs should be discounted to the present for comparison with current program expenditures but non-discounted values should be shown along with present values based on at least two different discount rates.

An incremental benefit-cost assessment framework has been developed by the Economic Services Branch to reveal the economic, distributional and environmental consequences of strategic abatement or prevention options. A key feature of this analytical framework is the presentation of the environmental/ecological effects, consequences and benefits of control actions in quantitative biophysical terms separately from estimates of the monetary values of these consequences. Determination of environmental/ecological effects may require a quantitative risk assessment. Determination of the distribution among stakeholders of costs and benefits associated with each scenario among relevant stakeholders is another important objective of this analysis.

In the following section, the primary steps and information needed to carry out a comprehensive benefit-cost assessment of environmental standards or policy/program options are identified and explained.

3 Key Steps and Information Requirements to Carry Out Benefit-Cost Assessments Option

The steps involved in conducting a comprehensive benefit-cost analysis of environmental standards and program options are summarized in Figure H.1.

Base case conditions and emissions forecasts are derived in Sections E and G. A base case scenario assumes that there would be no reductions in NO_X or VOC emissions from any sources after 1990 and that emissions would grow at the same rate as output in the source sectors is forecast to grow over the next 20 years.

Figure H.1 SUMMARY OF BENEFIT-COST ANALYSIS FRAMEWORK STEPS

1. **Identify benefit categories** and **quantifiers** relevant to environmental issue or problem.

2. Define **Initial or Reference Conditions** relevant to the issue or problem, against which consequences of remedial actions can be compared.

3. Postulate **Scenarios** with estimates of current and future environmental damages and effects associated with each scenario. One scenario should be a base-case scenario which includes initial or reference conditions. Other scenarios should represent proposed environmental programs or goals to be achieved.

4. Postulate potential feasible pollution abatement, pollution prevention, cleanup or remediation technologies or options (combination of technologies) that would achieve proposed standards or program goals (or move toward these objectives) and which form the basis for estimating the costs associated with each scenario. Costs to be estimated include **capital and other one-time developmental costs**, **operating and other recurring costs** associated with these technologies or options, and estimated **annual cash flows** (outlays and revenues) that are expected over a planning period.

5. **Quantify benefits** of proposed standards or programs in relevant biophysical units and terms. This step may involve the application of other analytical techniques including risk assessment.

6. Where possible, assign **monetary value estimates** to the quantities of benefits that are estimated.

7. Display, in tabular or graphic form, and on an annual basis, estimates of past and/or future costs and benefits, in relevant bio-physical units for each cost or benefit category, over the planning period of analysis. Where possible, estimate probabilities of each consequence.

8. Where costs and benefit values are to be compared, calculate (discounted) **present values of all monetized cost and benefit estimates**, using at least 2 potential discount rates, over the planning period.

9. Sum present values of monetized costs and benefits and compute differences between total present values of costs and benefits.

10. If value of monetized costs exceed value of all monetized benefits, the difference (value of benefits-costs) can be compared with non-monetized, but quantified, benefits to judge whether the added costs are commensurate with the quantified (but not monetized) benefits.

Two program scenarios are defined for analysis in the discussion paper entitled "Towards a Smog Plan for Ontario".

1. Implement existing NO_X-VOC emission reduction commitments plus reductions at specific low cost, readily available sources.

2. Implement reductions of NO_X-VOC emissions up to 45% from 1990 levels.

The corresponding NO_x and VOC emission reductions for these programs scenarios are summarized in Section G (subsection 6).

3.1 Control Costs

Descriptions of systems, technologies and activities that are proposed to implement environmental objectives or programs should precede cost estimates. Cost data and estimates of implementing standards or programs by specific sources should include the following:

1) **Capital Costs** - where possible, provide separate estimates of installation/labour, structures, land and equipment.

2) **Ongoing Operational Costs** - where possible, provide, on an annual basis, separate estimates of labour, materials, energy, purchased services. Also, provide estimates of staff time and other costs to collect data, store records, submit reports and other administrative activities to comply with requirements.

c) **One-time Development, Consulting or Start-up Costs** - provide separate estimates/data on one-time consulting, engineering, design, etc. costs not captured in above categories.

For most sources of emissions or other pollution releases, there are invariably a wide range of technology and system combinations that can be implemented to achieve various levels of release reductions and abatement. In order to provide a benchmark scenario that can be compared across sectors, estimates of the technologies and costs to achieve the lowest (technically) achievable emission rate (LAER) should be provided where possible.

3.2 Benefit Estimation

Environmental management policies, programs and activities which result in real or perceived improvements in environmental quality or protection of natural resources yield:

- **Private Benefits** — reduced inputs to the production process or other activity that causes the environmental problem; increased recovery of materials for reuse, recycling; increased productivity with existing equipment and inputs realized by companies or individuals who make investments in environmental protection or energy conservation. They can be measured as increased revenues, profits, wages or other beneficial

consequences. Examples include sale of recovered by-products, reduced inputs and costs or enhanced goodwill or public relations, increased property values.

- **Public Benefits** — actual and perceived increases in welfare and quality of life received by society as a result of reduced risk of disease or death, increased or enhanced environmental amenities and services, and other beneficial effects which are valuable to society but are not directly manifested in terms of increased net incomes or profits to regulated parties.

- **Local or Regional Economic Activity and Employment** - Expenditures made by emissions sources, whether they be individuals, corporations or groups, to comply with requirements or by government to implement projects can generate economic activity and employment. While increased economic activity or employment in a local community may not increase net benefits to society, economic activity and employment effects of compliance and government program expenditures are important considerations in public policy development and planning.

Private benefits are generally associated with the compliance technologies and control programs that are reviewed or postulated in order to assemble or estimate costs. Local/regional economic activity and employment are also driven by the abatement or prevention technologies chosen and expenditures made to implement them. The most difficult and challenging estimates to generate are the public benefits associated with proposed standards or existing programs. Nevertheless, useful and systematic data and estimates of the public, non-marketed beneficial consequences of standards or control programs can be developed using the procedures discussed below.

Public benefits must be **identified**, **quantified** and, where possible, **valued** in monetary terms. Using the Damage Function approach, empirical estimates of the benefits of environmental management are expressed primarily as reduced damages from a base-case, unreduced emission forecast scenario by two separate sets of estimates:

- **physical quantities** of health effects and other environmental damages reduced or avoided, increased crop production or productivity, and

- **monetary values** attributed to reduced damages or other beneficial biological or physical effects.

The key benefit categories that are quantified in this exercise are increased crop production, increased ornamental plant values, increased tree seedling production and reductions in adverse human health effects (mortality and morbidity measures) due to reduced exceedances of the ground level ozone standard. Estimates of vegetation-related benefits are based on a complete elimination of exceedances above 80 ppb ground level ozone.

Based on an earlier study (Donnan, 1993), it was determined that crop and ornamental productivity in Ontario could be increased by $17 to $70 million annually if the existing O_3 air

quality criterion of 80 ppb was achieved. The economic magnitude of O_3 impacts on vegetation in Ontario and other countries is now being re-evaluated, as part of the standards setting reviews in Canada, the U.S. and Europe. Although these studies are not yet completed, they do substantiate the damaging effects of O_3 on vegetation in Ontario.

Only human mortality and morbidity effects associated with estimated reductions in PM_{10} and ground level ozone exposures are quantified and valued. Potential reduced damages to materials associated with reductions in ground-level ozone exceedances or PM_{10} concentrations could not be quantified.

Human health related effects are estimated in Section C for the base case and the two program scenarios. Besides mortality, morbidity effects include bronchitis in adults or children, hospital admissions, reduced activity days, asthma symptom days and acute respiratory symptom days.

In the present study, benefits estimated are the differences (reductions) between various health and environmental effects that occur at the base case (unreduced emissions) forecast level and the damages and effects that occur at levels realized under the two program scenarios.

Monetary values constitute a set of weights that can be ascribed to the various benefit categories for the following reasons. First, monetary values transform estimates of different effects that are measured in widely varying incommensurate units into a common unit that can be aggregated and compared with each other and with the costs of implementing control or management programs. Second, monetary values provide an indication of the relative social or economic importance of the benefits relative to other goods and services. Other units of value or weight can be applied to the biophysical estimates of benefits but monetary values are widely understood and accepted measures of social value.

Estimates of the monetary values associated with reduced mortalities and morbidity effects are presented in the next section.

4 Monetization of Reduced Health Effects

Monetary values are fundamentally based on the maximum amount people would be willing to pay (WTP) to obtain a particular good, service or benefit. Where market prices are available for relevant benefit measures or can be used to determine the value of a good or service (eg. agricultural crops, materials and structures, costs of medical services etc.), monetary value estimates will be uncontroversial and generally acceptable. Where benefit categories are non-marketed or public goods with no market prices associated with them (eg. mortality, reduced activity days caused pollutants, perceptions of environmental quality, etc.), specialized methods and techniques must be applied to estimate the relevant WTP monetary values. One method is to use expenditures on marketed goods and services that are complements to environmental quality to infer the value of increased environmental protection. Another is to ask people carefully designed questions to elicit their willingness to pay values for non-marketed environmental goods and services.

The monetary values are estimated for human health benefits. Inhalable particulates (IP) are known to cause mortalities and other non-fatal illnesses and other acute morbidity effects. Ground level ozone (O_3) is linked to a variety of non-lethal morbidity effects as well as vegetation and crop damages. Reduced damages to structures and materials and private benefits that could be realized by firms that invest in pollution abatement have not yet been estimated.

The value of the human health benefits associated with the two potential Ontario Smog Plan scenarios were calculated using dose-response functions from Chestnut and Ostro (June 1995) as part of a study on clean vehicles and fuels prepared for the Canadian Council of Ministers of the Environment (CCME). Procedures to estimate the mortality and morbidity effects of the base case emission forecast and the two program scenarios are presented in Section C.

Monetary values associated with each type of health effect (mortality and ten distinct morbidity effects) are shown in Table H.1. These unit values are derived from Lang et al. October 1995) and include "high", "central" and "low" values per incident or death.

Table H.1: Estimated Morbidity and Mortality Monetary Values per Life/Incident

	LOW ($)	CENTRAL ($)	HIGH ($)	Type
MORTALITY				
Age Weighted Average	2,400,000	**4,000,000**	7,900,000	WTP
MORBIDITY				
Adult Chronic Bronchitis	174,000	**279,000**	442,000	WTP
Cardiac Hospital Admission	4,200	**8,300**	12,500	COI
Respiratory Hospital Admission	3,300	**6,500**	9,800	COI
Emergency Room Visit	300	**600**	900	COI
Child Acute Bronchitis	180	**360**	540	COI
Restricted Activity Day	35	**70**	105	WTP
Asthma Symptom Day	15	**41**	68	WTP
Minor Restricted Activity Day	18	**30**	50	WTP
Acute Respiratory Symptom Day	7	**14**	20	WTP
Probability for Uncertainty	33%	**34%**	33%	

WTP = Willingness to Pay, COI = Cost of Illness

Source: Environmental and Health Benefits of Cleaner Vehicles and Fuels, Supplemental Report 3, Hagler Bailly Consulting, August 1995.

As shown in Table H.1, these values represent the amounts that individuals are willing-to-pay (WTP) to reduce the **risk** of death or to avoid the specific morbidity effects estimated in Table H.1. Other morbidity effects such as hospital admissions or cases of bronchitis in children and adults are based on treatment-related costs plus lost wages due to the illness (Cost of Illness values) which have been adjusted to willingness-to-pay equivalent values by multiplying COI values by a factor (WTP/COI) of 2.

All of the steps taken to estimate reduced health effects and their values are subject to uncertainty. Lang et al. (October 1995) describe and carry out uncertainty analyses to arrive

at a range of estimates of monetary values of health effects. Equal probabilities of 33% were assigned to high, medium and low estimates because alternative estimates appear equally reliable. For the present estimates, the "central" values shown in Table H.1 are used to convert the estimated health effects in Section C to monetary values.

Tables H.2 and H.3 mirror health effects estimates tables in Section C. Table H.2 is an intermediate set of estimates for the base case forecast ("Unreduced Emissions") plus the two program scenarios. Table H.2 shows the monetary value of **increases** in human health effects that occur in 2015, **relative to the year 1990**, if no reductions in emissions were implemented. Table H.2 also shows that, even if the "Existing and Readily Available Reductions" to emission reductions were achieved, health effects and the values associated with them would still increase relative to 1990, although the number and value would be substantially lower than the "Unreduced Emissions" base-case forecast. The estimated values of the health-related benefits are summarized in Table H.3. Implementing the 45% reduction to achieve a target reduction would result in a reduction in annual mortalities and morbidities in 2015, **relative to 1990**, that could total as much as $717 million.

For example, the number of people in Ontario with chronic bronchitis will have increased if no initiatives are undertaken to reduce O_3 and IP between 1990 and 2015. The value associated with the increased incidence of chronic bronchitis is $132.4 million per year. If the "Existing and Readily Available Reductions" are all implemented, then the incidence of chronic bronchitis in Ontario would still increase by 2015, but to a lesser extent, and the monetary value of the increased morbidities would be about $21 million per year. Under the final scenario, asthmatics realize benefits relative to 1990, which would range from $93 million to $198 million. The incidence of asthma attacks would drop below those occurring during the present time so the value of the reduced asthma incidence would range from $93 to $198 million.

Table H.3 shows the ranges of values of reduced health effects in 2015 **relative to the quantities and values estimated for the "Unreduced Emissions" base-case forecast**. A summary of this table is presented in the discussion paper. The figures represent the amounts that people would be willing to pay in 2015 to gain the reduced morbidities and mortalities. Tables C.5 and C.6 in Section C shows the number of reduced health effects under each type **relative to the "Unreduced Emissions" base case forecast for 2015.**

These estimates have two key qualifications. First, they represent the "central" unit values for the various health effect measures. Much wider ranges of value can be estimated by applying the "low" or "high" values to the range of health effects estimated in Section C. Thus, the uncertainty range associated with these values can be very wide. Second, these benefits are estimated for the year 2015. The monetary values indicated apply to the year 2015. If the values of these benefits are to be compared with abatement or prevention costs that will be incurred in earlier years (eg. 1997 - 2000), then the value of the benefits in 2015 must be discounted to make them equivalent to the abatement costs that would be incurred in the present.

To show the effect of discounting, the value estimates from Table H.3 are discounted using a 5% real discount rate and summarized in Table H.4. A 5% real discount rate was used because people do not discount the value of future health effects to the same extent as they would other goods, services or incomes received in the future. The values in Table H.4 are the 1996 willingness-to-pay values of health benefits that are realized in 2015.

Based on the second program scenario, Reduce Emissions by 45%, over 95% of the value of reduced health effects are associated with PM_{10}.

Table H.2

Undiscounted Monetary Values of (Increased)/Reduced Health Effects of PM_{10} and Ozone Emissions Under the Base-Case Forecast and Two Program Scenarios Relative to 1990 ($ Millions)

SCENARIOS	Mortality		Chronic Bronchitis[1]	Hospital Admissions[2]	Emergency Room Visits (ERV)	Asthma Symptom Days	RADs & MRADs	Acute Respiratory Symptoms Days	Total Symptom Days[3]	Total Morbidity[4]	Morbidity and Mortality
	O_3	PM_{10}									
Base Case: Unreduced Emissions from 1990 (growth only)	($8.7) ($18.9)	($277.1)	($132.4)	($0.5) ($0.6)	($1.5) ($1.5)	($1.6) ($2.0)	($31.1) ($32.5)	($19.9) ($21.5)	($52.5) ($56.1)	($186.9) ($190.6)	($472.7) ($486.6)
Existing and Readily Available Reductions (with growth)	($1.2) ($3.1)	($43.7)	($20.9)	($0.1) ($0.1)	($0.2) ($0.2)	($0.2) ($0.1)	($4.9) ($5.2)	($3.1) ($3.4)	($8.2) ($8.7)	($29.4) ($30.0)	($74.4) ($76.8)
45% Reduction from 1990 NO_x and VOC Emissions	$9.8 $19.7	$194.5 $414.8	$92.9 $198.3	$0.4 $0.8	$1.1 $2.3	$1.3 $2.7	$22.3 $47.5	$14.5 $30.8	$38.2 $80.9	$132.5 $282.3	$336.9 $716.8

NOTE:
All monetary values were calculated using the "Central" values in Lang et al., October 1995.

[1] Chronic Bronchitis = *Adult Chronic* Bronchitis + *Child* Bronchitis. All changes in bronchitis occurrences are attributed PM_{10}.
[2] Hospital Admissions = Cardiac + Respiratory
[3] Total Symptom Days = Asthma Symptom + Acute Respiratory + Restricted Activity Days (RADs) + Minor Restricted Activity Days (MRADs)
[4] Summation all morbidity values in table.

Table H.3

Ranges of Undiscounted Annual Values of Reduced Health Effects Relative to the "Unreduced Emission (with Growth)" Base-Case Forecast for 2015 ($ Millions)

SCENARIOS	Mortality		Chronic Bronchitis[1]	Hospital Admissions[2]	Emergency Room Visits (ERV)	Asthma Symptom Days	RADs & MRADs	Acute Respiratory Symptoms Days	Total Symptom Days[3]	Total Morbidity[4]	Morbidity and Mortality
	O_3	PM_{10}									
Existing and Readily Available Reductions (with growth)	$7.5 - $15.7	$233.4	$111.5	$0.4 - $0.5	$1.27 - $1.29	$1.3 - $1.9	$26.2 - $27.4	$16.8 - $18.1	$44.3 - $47.3	$157.5 - $160.7	$398.4 - $409.8
45% Reduction from 1990 NO_x and VOC Emissions	$18.5 - $38.6	$471.6 - $691.9	$225.4 - $330.7	$0.9 - $1.4	$2.6 - $3.8	$2.9 - $4.7	$53.4 - $80.0	$34.4 - $52.3	$90.7 - $137.0	$319.5 - $472.9	$809.6 - $1,203.4

NOTE:
All monetary values were calculated using the "Central" values in Lang et al., 1995.
[1] Chronic Bronchitis = *Adult Chronic* Bronchitis + *Child* Bronchitis. All reductions in bronchitis are attributed solely to PM_{10} reductions.
[2] Hospital Admissions = Cardiac + Respiratory
[3] Total Symptom Days = Asthma Symptom + Acute Respiratory + Restricted Activity Days (RADs) + Minor Restricted Activity Days (MRADs)
[4] Summation of all morbidity effects (all health outcomes except mortality).

Table II.4

Present Values of Ranges of Annual Monetary Values for Reduced Health Effects Relative to the "Unreduced Emission (with Growth)" Base-case Forecast for 2015 ($ Millions)

SCENARIOS	Mortality		Chronic Bronchitis[1]	Hospital Admissions[2]	Emergency Room Visits (ERV)	Asthma Symptom Days	RADs & MRADs	Acute Respiratory Symptoms Days	Total Symptom Days[3]	Total Morbidity[4]	Morbidity and Mortality
	O_3	PM_{10}									
Existing and Readily Available Reductions (with growth)	$3.0	$92.4	$44.1	$0.2	$0.5	$0.5	$10.4	$6.6	$17.5	$62.3	$157.6
	$6.2			$0.2	$0.5	$0.7	$10.8	$7.2	$18.7	$63.5	$162.1
45% Reduction from 1990 NO_x and VOC Emissions	$7.3	$186.6	$89.2	$0.3	$1.0	$1.1	$21.1	$13.6	$35.9	$126.4	$320.4
	$15.3	$273.8	$130.9	$0.5	$1.5	$1.9	$31.7	$20.7	$54.2	$187.1	$476.2

NOTE:
All monetary values were calculated using the "Central" values in Lang et al., Oct. 1995.
Present Values were calculated using 5% discount rate over 19 years.

[1] Chronic Bronchitis = *Adult Chronic* Bronchitis + *Child* Bronchitis. All monetary values for bronchitis are attributed solely to PM_{10} reductions.
[2] Hospital Admissions = Cardiac + Respiratory
[3] Total Symptom Days = Asthma Symptom + Acute Respiratory + Restricted Activity Days (RADs) + Minor Restricted Activity Days (MRADs)
[4] Sum of all health outcomes in the table except mortality.

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